
Volume I Preface

The Environmental Assessment (EA) for the Ambatovy Project (the project) is intended to meet the information requirements outlined in the Terms of Reference (ToR) in an easily understood and comprehensive package of information. Information is presented in 11 volumes that address specific subject areas. The volumes are as follows, and the structure of each volume is depicted in Figure 1:

- Volume A: Introduction
- Volume B: Environmental Assessment - Mine
- Volume C: Environmental Assessment - Slurry Pipeline
- Volume D: Environmental Assessment - Process Plant
- Volume E: Environmental Assessment - Tailings Facility
- Volume F: Environmental Assessment - Port Expansion
- Volume G: Environmental Assessment - Cumulative Effects
- Volume H: General Appendices
- Volume I: Physical Appendices
- Volume J: Biological Appendices
- Volume K: Social Appendices

Volume A introduces the EA and contains study area and methodological information pertaining to all disciplines and all project components.

For the convenience of readers who wish to read only specific parts of the EA, each of the assessment volumes B through F include descriptions of the project component being addressed. Therefore, a reader who is interested in one particular component may read the corresponding assessment volume.

Volume G contains a cumulative effects assessment that addresses the combined effects of the project components and cumulative effects of the whole project plus other foreseeable developments in Madagascar.

Where appropriate, the EA refers to separate documents in volumes H through K called Appendices, which contain additional technical and baseline information. These volumes also contain environmental assessment appendices for some disciplines with information of relevance to the environmental assessment for multiple components of the project. The glossary, acronyms and references for all volumes are listed in Volume H Appendices 12 and 13.

Figure 1 Environmental Impact Study Structure for the Ambatovy Project

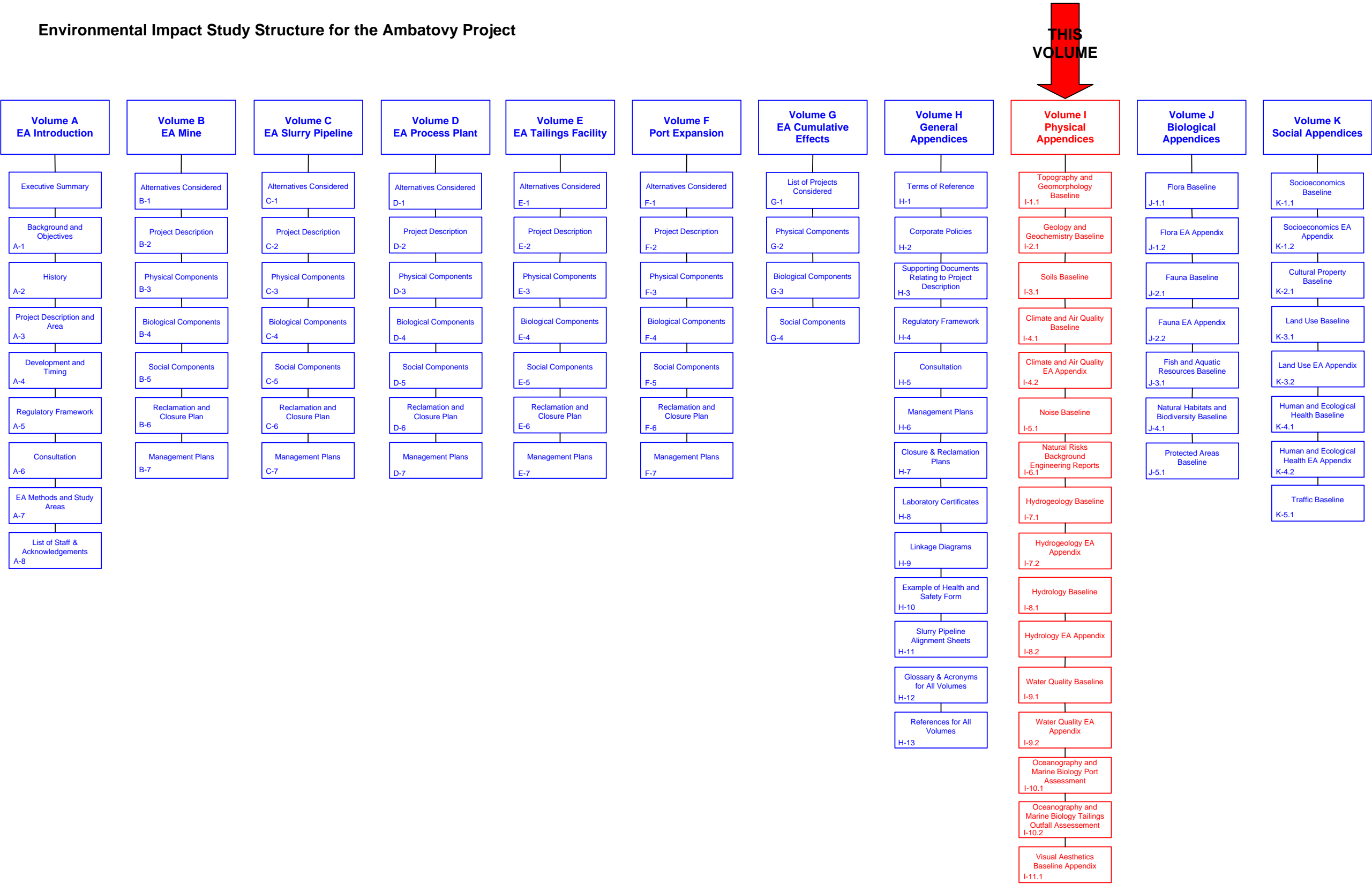


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VOLUME I: PHYSICAL APPENDICES

APPENDIX 1.1

TOPOGRAPHY AND GEOMORPHOLOGY BASELINE

Submitted to:

Dynatec Corporation

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1 INTRODUCTION

The topography of Madagascar has been shaped by geomorphologic processes controlled by several factors, including climate, underlying geology, structural features, erosion processes including the action of wind and water, and human activity. Topography is highly variable in the Ambatovy Project (the project) areas.

The topography and geomorphology of the landscape influences the way surface and groundwater flows, the way soils and biotic communities develop, the way the land can be used, and the aesthetic qualities of the landscape for both residents and visitors.

2 METHODS

Topographic and geologic maps, conventional photographs, aerial photographs, field reports and site visit notes have been used to develop an understanding of the baseline topography and geomorphology of the project areas. The geomorphology of the project regions is documented based on the Atlas of Madagascar (1969), Jolly et. al. (1984) and Besairie (1967). The topography of the mine area was initially summarized by Phelps Dodge in 1999. The topography of other project areas has been described based on environmental assessment and engineering field reports prepared in 2004 and 2005.

3 RESULTS

3.1 GENERAL

Madagascar can roughly be divided into five landscape/topographic zones:

- The east coast is characterized by a narrow alluvial plain, supporting tropical montane forests in some areas, and steep coastal topography in other parts due to a sharp fault found along Madagascar's east coast.
- The west coast is characterized by coastal plains.
- The central highlands form the interior of the island, and two-thirds of the country as a whole, with altitudes generally ranging from about 600 m to more than 1,800 m.
- The Tsaratanana Massif region at the north end of the island contains, at 2,880 m, the highest point and, north of this, the Montagne d'Ambre (Ambohitra), which is of volcanic origin.
- The southwest portion of the country, including the Mahafaly Plateau, has semi-desert characteristics.

3.2 MINE SITE

The mine is located in the central highlands, about 85 km inland of the Indian Ocean and 90 km east of Antananarivo. The Ambatovy and Analamay project areas are located on the west rim of the Ankay Range, on one of two escarpments that separate the central plateau from the lowlands of the east coast. The escarpments extend in a north-south direction over much of the length of Madagascar, and border the eastern flank of the central plateau. The escarpment in the project region is characterized by hilly terrain, with elevations over 1,100 m, as well as numerous rivers and streams.

The geomorphologic processes acting on the region are controlled by several factors, including climate, underlying geology, structural features such as the presence of lineaments, and erosion processes. Lineaments are structural linear alignments, such as fault zones, that appear to control the alignments of hills and valleys in the area.

The mine area includes the eroded remnants of a plateau located at an elevation of about 1,100 metres above mean sea level (masl). The plateau is flanked to the west by the broad alluvial plain of the Mangoro River and to the east by the Torotorofotsy Wetlands and forested hills.

A ridgeline plateau and flanked by hills and valleys characterizes the geomorphology of the Ambatovy and Analamay ore bodies. The plateau covers the northeastern portion of the Ambatovy ore body due to the presence of an erosion-resistant ferricrete crust. The plateau surface is fairly uneven with numerous depressions that form ephemeral pools. The ferricrete layer thins on the flanks of the plateau and hills, thus becoming more susceptible to erosion. Zones of weakness associated with faults, fractures and dikes are present at the site.

The geomorphology of the mine area is characterized by relatively steep slopes, rolling hills and alluvium-filled valleys. Tectonic processes, the forces involved in deformation of the earth's crust, are responsible for the presence of faults, fractures and dikes. These features create zones of weakness that are easily eroded. Erosion preferentially occurs along zones of weakness and can contribute to the headward advance of rivers and streams, which, in turn, extends and deepens the valleys.

The hills within this area are composed of laterite that is susceptible to erosion when wet, especially in the presence of moving water. Groundwater infiltrating downward flows along the interface between the bedrock and the laterite. It is the process of preferential flow which causes erosion in the form of lavaka. The lavaka contribute to the linear alignment of the valleys along these zones of weakness.

Lavaka are erosion features that have had a pronounced impact on the geomorphology of many areas in Madagascar, including areas near the mine site. Lavaka are deep gullies formed by movement of groundwater at the base of the hills. Detailed discussions regarding the development and control of lavaka are found in references such as Wells and Andriamimaja (1997).

West of the mine, along the proposed water intake line from the Mangoro River, the topography flattens, and valley bottoms widen.

3.3 SLURRY PIPELINE

The Slurry Pipeline runs from the central highlands of Madagascar, through the Torotorofotsy Wetlands complex, passes through a series of watersheds with steep valleys characterized by granite outcrops and continues over topography with gradually lower relief until reaching the flat coastal dune structures of the Madagascar east coast.

The geomorphology of the Torotorofotsy Wetlands system is characterized by rolling hills and alluvium-filled valleys. The valleys have been partially closed off, resulting in thick deposits of alluvial material. The closed valleys are probably the result of tectonic activity. The valley fill is composed of a thick (up to 80 m) sequence of stream deposits including clay, silt, sand and gravel. Valleys in the Torotorofotsy Wetlands are predominantly marshlands and do not appear to be advancing due to headward erosion and lavaka formation.

The topography of the central highlands has been shaped by tectonic forces and erosion. Steep-sided, irregularly shaped valley formations predominate for much of the length of the pipeline. Slopes reach a typical maximum of 45 degrees. Bedrock is frequently shallow and is exposed in many streambeds. The principal underlying geological formations are gneisses, granite gneisses (compound gneiss), granites and migmatite granites. Gneiss outcrops correspond to the low points of the relief whereas the granites are usually present along high points in the relief.

Lavaka erosion formations and other areas exhibiting slope failures are present in several parts of the pipeline route, especially in areas below an elevation of 910 m where more highly erodible rock material is present.

3.4 PROCESS PLANT SITE

The east coast of Madagascar generally consists of narrow bands of lowlands, about 50 km wide, formed from the sedimentation of alluvial soils. The process plant is located about 2 km from the coast. The area is characterized by flat, coastal topography of low to medium relief, dominated by sandy dunes. The elevation of the plant site varies between 6 and 10 masl.

The geomorphologic processes acting on the plant local study area (LSA) are controlled by several factors, including climate, underlying geology, water action and other erosional processes. Dunes and coastal ponds or wetlands are aligned parallel to the coast in long sequences. Groundwater is relatively close to the surface, making low-lying topography wet during rainy seasons. The plant site is about 1 km west of the Pangalanes Canal, a prominent topographic feature running north and south along the coast.

3.5 TAILINGS FACILITY

A series of three valleys west of Toamasina make up the area of the planned tailings facility. The valleys are characterized by moderately steep, forested hillsides and valley walls which descend into flat, wide valley floors. The

highest elevation within the valleys is 90 masl at the western end, and the lowest elevation is 4 masl, in the far eastern portion of the site. The valley floors, in particular the wide, wet floor of the northern valley, have been developed into rice paddies. Drainage flows in an easterly direction from the valleys along a natural gradient of less than six degrees (10%) towards the north to south trending Ambolona (Sangalaoatra) River.

Much of the topography of the site is dictated by the underlying geology; the major rock types in the area are gneiss, biotite gneiss, migmatite and mica schist. These rocks have been intruded by north to south trending amphibolite and schist zones. Surficial deposits consisting of alluvium including clays, sand and gravel occur within and along drainage features and rivers.

4 REFERENCES

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VOLUME I: PHYSICAL APPENDICES

APPENDIX 2.1

GEOLOGY AND GEOCHEMISTRY BASELINE

Submitted to:

Dynatec Corporation

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1 INTRODUCTION

This section addresses the baseline conditions for geology and geochemistry for the Ambatovy Project (the project). Topography and geomorphology are addressed separately in Volume I, Appendix 1.1.

An understanding of the regional and local geology is an important element of the mine project baseline description. The geology dictates the characteristics of the ore body and influences the hydrology, geochemistry and topography of the area. In addition, the geological features of the deposit control the composition of natural and mine-drainage waters (Plumlee et al., 1999).

A geochemical characterization program was performed on ore, mine rock and tailings samples from the Ambatovy and Analamay deposits. The purpose of the geochemical testing was to determine the chemical composition and assess the environmental stability of these materials. In particular, the goals were to assess the following:

- the chemical behavior of the materials when exposed to the environment; and
- the potential of these materials to impact surface water and groundwater quality by leaching chemical constituents.

The geochemistry section of this appendix describes the methods used in selecting samples for these tests, the types of tests performed, the test results, and interpretation of test results. The data generated from these tests were used to identify potential parameters of concern that may be released into groundwater and surface waters and cause an adverse impact to the environment.

Two geochemical characterization programs were conducted on ore and mine rock, both in support of the Environmental Assessment (EA). The first took place in the late 1990s on behalf of Phelps Dodge Madagascar (PDM). The second effort was completed on behalf of Dynatec as part of the current EA. The results from both investigations were combined and are presented in this appendix.

Phelps Dodge Madagascar and Dynatec also conducted separate geochemical characterization programs for the tailings. However, only the results from the Dynatec investigation are presented and discussed as the Dynatec tailings were generated using metallurgical testing considered representative of the expected operational processing methodology.

2 METHODS

2.1 GEOLOGY

At the mine site, three major exploration campaigns including drill programs were completed. These include:

- Groupement d'Etude de Nickel de Moramanga (GENiM) explorations (1970s);
- PDM explorations (1995-1998); and
- current Dynatec explorations, which began in 2003.

The results of these campaigns, in combination with geologic maps and available literature, have been used to develop an understanding of the baseline geology of the mine, process plant and tailings areas. Geologic resources in other project areas are not expected to be affected by project activities and do not require a baseline assessment.

2.2 GEOCHEMISTRY

2.2.1 Geochemical Characterization Program

2.2.1.1 Mine Rock and Ore

The geochemical characterization programs for ore and mine rock conducted by PDM and Dynatec were very similar in scope, and included the following components:

- chemical analysis of solids:
 - PDM: whole rock analysis by x-ray fluorescence (XRF);
 - Dynatec: chemical analysis by a combination of acid digestion/atomic absorption (AA) and sodium fusion/inductively coupled plasma (ICP);
- mineralogical characterization by x-ray diffraction (XRD);
- determination of the acid-generating potential by acid-base accounting (ABA);
- chemical analysis of entrained water in the sample slurries (Dynatec only);

- single-stage short-term leach testing by synthetic precipitation leaching procedure (SPLP) (United States Environmental Protection Agency Method 1312, USEPA 1995); and
- consecutive SPLP (PDM only).

Sample selection procedures, analytical results and interpretation of analytical results are presented in the following sections.

2.2.1.2 Tailings

The geochemical characterization for the tailings conducted by Dynatec included the following components:

- chemical analysis of solids;
- acid-base accounting;
- chemical analysis of liquids:
 - entrained water from pilot plant test work;
 - supernatant;
 - drained seepage from settling test; and
- three-stage sequential leaching.

2.2.2 Sample Selection

2.2.2.1 Mine Rock and Ore

Phelps Dodge Madagascar conducted geochemical characterization on ten composite low grade ore samples obtained from exploratory drill cores at the Ambatovy deposit. The samples were selected and composited from about 1,000 core samples obtained for purposes of metallurgical evaluation. Testing was performed on one composite sample of each major rock type identified in the lithological classification protocol used by PDM, as well as two additional saprolite samples and one additional ferralite sample. The samples were identified and classified based on their lithological descriptions, mode of occurrence, and chemical composition.

Dynatec selected four composite samples from the Ambatovy West deposit, representing the major types of mineralization. These materials were bulk composite samples which had been prepared for metallurgical test work at Dynatec's pilot plant facilities in Fort Saskatchewan, Canada. In addition, two ore samples were tested from drillhole number DAN 156 located in the

Analamay Centre deposit. These materials were collected during the 2004 resource drilling program and were also part of the samples selected for batch metallurgical test work in Fort Saskatchewan.

The sixteen samples submitted for geochemical characterization are listed in Table 2.1-1.

The Ambatovy samples listed in Table 2.1-1 represent a pseudo-stratigraphic sequence of the Ambatovy ore body. It was developed by arranging most of the samples in order of increasing magnesium oxide content, which was used as a measure of alteration. The top layer represents the most altered lithologic unit, whereas the bedrock is the unaltered parent material. The bauxite and kaolinite clay occur as lenses and veins within the ferralite. However, kaolinite clay may also be present as a layer just above the low-magnesium saprolite. In addition, bauxite and kaolinite clay are absent in some portions of the deposit.

Table 2.1-1 Sample Characteristics and Description

Sample Origin	Sample ID	Material Category	Deposit
PDM	G	Ferricrete and Grenaille	Ambatovy
Dynatec	FT-Am FB-Am	Ferralite	Ambatovy
PDM	FER NFER		
PDM	AFER	Bauxitic Material	Ambatovy
PDM	KAO	Kaolinitic Clay	Ambatovy
Dynatec	LMS-Dy	Low-Mg Saprolite	Ambatovy
PDM	LMS-PDM		
Dynatec	SAP-Dy	Saprolite	Ambatovy
PDM	SAP-PDM Pit 8 SAP Hard SAP		
PDM	Bedrock	Bedrock	Ambatovy
Dynatec	FT-An	Ferralite	Analamay
	FB-An		

Notes Suffixes "PDM" and "Dy" are used to distinguish between Phelps Dodge and Dynatec samples of the same lithology.
 Suffixes "Am" and "An" are used to distinguish between Dynatec Ambatovy and Analamay samples from the same lithology.
 Samples without a suffix were part of the PDM program.

2.2.2.2 Tailings

Geochemical testing was conducted on several samples of neutralized tailings from Dynatec's pilot plant processing of Ambatovy ore. The samples were submitted to Knight Piesold and the University of British Columbia for

geotechnical testing, after which geochemical samples were obtained and analyzed by either Dynatec or Lakefield.

2.2.3 Sample Representativeness

2.2.3.1 Mine Rock and Ore

The representativeness of the ten composite PDM samples was evaluated by comparing their chemical composition to that of identical rock types contained in the PDM exploration drill core data base. The compositional parameters used for this comparison were nickel (as nickel oxide) and magnesium (as magnesium oxide), as a representative trace metal and major element, respectively. Both nickel oxide and magnesium oxide were used in delineating the individual rock types during the exploration campaign, and a large data base, therefore, was available. Statistical analysis demonstrated that within each rock type, nickel and magnesium are distributed normally, and that multiple populations are absent. This indicates that nickel and magnesium are useful descriptors of individual lithologies.

Standard statistical parameters were calculated for each rock type using the PDM exploration database, which at the time consisted of 15,668 core samples. A compositional range was defined using nickel oxide and magnesium oxide, extending from the mean (n) minus 2 standard deviations (s) to the mean plus 2 standard deviations (i.e., $n-2s$ to $n+2s$). This range covers ≥ 95 percent of all samples within each lithology, a selection considered sufficiently broad for characterization purposes. The nickel oxide and magnesium oxide contents of the ten composite samples were then compared to this range for the determination of representativeness.

Both the nickel (as nickel oxide) and magnesium (as magnesium oxide) content for each lithologic unit were below the upper 95th percentile and fell within the $n-2s$ to $n+2s$ range. Approximate percentiles of nickel oxide and magnesium oxide content for the ten PDM samples are presented in the Table 2.1-2.

Table 2.1-2 Sample Representativeness

Sample ID	Percentile Based on Nickel Content	Percentile Based on Magnesium Content
G	41	23
FER	6	31
AFER	13	46
NFER	63	86
KAO	65	87
LMS-PDM	40	69
SAP-PDM	61	49
Pit 8 SAP	87 (used SAP data)	41 (used SAP data)
Hard SAP	32 (used SAP data)	86 (used SAP data)
Bedrock	75	24

The above list demonstrates that the sample representativeness is variable. The percentiles calculated using nickel suggest that the ferralite, bauxite and hard saprolite samples are at the low end of the nickel range, whereas the Pit 8 saprolite and bedrock samples represent high-end nickel concentrations. The percentiles calculated for magnesium indicate that the ferricrete and bedrock samples are at the low end of the magnesium range, whereas the ferralite, kaolinite clay, and hard saprolite samples represent magnesium contents near the upper end of the compositional range observed in the exploration data base.

The Dynatec samples were derived from composited subsets of ore samples prepared from the work conducted on developing the ore deposit model throughout Ambatovy and Analamay. The ore samples represent material collected from about 22 000 metres of drill core samples during the 2003 and 2004 drilling campaign. The Dynatec drilling campaign involved a total of 224 holes drilled in Ambatovy and 321 holes drilled in Analamay, which supplemented the drilling campaign conducted by Phelps Dodge. As a result of sample preparation, it is Dynatec's opinion that the geochemical characterization program was conducted on composite samples that are representative of the Ambatovy and Analamay ore bodies.

2.2.3.2 Tailings

The tailings samples included in Dynatec's geochemical characterization program are considered to be representative of expected operational processing conditions. Due to the very small number of individual samples, no quantitative assessment of sample representativeness was conducted.

2.2.4 Geochemical Characterization Methodology

Chemical composition - The chemical analysis was used to determine the chemical characteristics of the different lithologies, and to assist in evaluating the relative and absolute leachability of the various materials. The results from these analyses were also used to assess the representativeness of the samples, as described previously.

Mineralogical analysis - Mineralogical analysis was used to determine the relative abundance of the major mineralogical components in the samples. This analysis provides a frame of reference for evaluating the results from acid-base accounting or static leaching. In combination with the bulk chemical characteristics, the sample mineralogy was used to explain and predict the leachability of the materials tested.

Acid-Base Accounting (ABA) - ABA analysis is a common screening technique used in the mining industry to provide a first indication of the acid-generating potential of a material. It consists of a series of tests that identify the acid-generating components, such as reactive sulphide minerals, and acid-neutralizing components, such as carbonate minerals within a geologic material or mining waste. Based on the ABA results, a general determination is made whether more extensive testing (e.g., kinetic testing) is necessary to more accurately evaluate the acid-generating potential of a material.

The acid-generating potential (AGP) is calculated from measurement of a variety of sulphur species, including total sulphur, sulphide sulphur, sulphate sulphur, and residual sulphur. These sulphur species generally are analyzed by Leco furnace following a series of partial digestion steps. The acid-neutralizing potential (ANP) is determined by digestion of the sample with excess acid.

Analysis of entrained water (ore and tailings), tailings supernatant and tailings seepage - Chemical analysis of the various solutions was conducted to characterize the water associated with tailings as well as with the ores during ore feed preparation.

Leach testing - To evaluate the potential for short-term leaching and allow for comparison with effluent limits, all mine rock and ore samples were submitted to a single-stage Synthetic Precipitation Leaching Procedure (SPLP – U.S. Environmental Protection Agency (EPA) Method 1312). Longer-term leaching behavior was evaluated qualitatively by subsequently performing three consecutive SPLP tests on the ten mine rock PDM samples as described below.

Similarly, sequential leach testing was performed on two tailings samples using deionized water.

The SPLP procedure was designed by the U.S. EPA to determine the mobility of chemical constituents by simulating interaction between natural precipitation and a solid material (U.S. EPA, 1995). As such, it has been accepted by U.S. EPA as a standard method, although it has no status in terms of enforcement, nor have SPLP criteria been promulgated.

According to the standard SPLP procedure, the solid sample is leached with an amount of extraction fluid equal to 20 times the weight of the solid phase while being agitated for an 18-hour period. For locations that are representative of areas in which acidic rain may occur, the synthetic extraction fluid consists of a dilute sulphuric/nitric acid mixture with an initial pH of 4.20 ± 0.05 .

To simulate rainwater in areas not affected by industrial urban activity, a leachant with an initial pH of 5.00 ± 0.05 is used. Although the precipitation at the project area is representative of non-industrial conditions (i.e., a pH of about 5.5), the lower pH was used for the PDM samples, which results in more aggressive leaching and is, therefore, more conservative.

For the Dynatec test work, the SPLP extraction medium had a pH between 5 and 6, which would represent the pH of normal precipitation in an undeveloped area. In both cases, the lixiviant was unbuffered, and therefore the initial pH can change as a result of interaction with the sample material. The consecutive SPLP tests were performed by exposing the samples to three sequential leaches using fresh lixiviant during each episode.

Chemical analysis of the leachates from the initial, single-stage SPLP testing of mine rock/ore as well as from the sequential leach testing of tailings was comprehensive, and included all major ions as well as a large number of trace metals. Analyses performed on the consecutive SPLP leachates from the PDM samples included leachate pH, dissolved, chromium, iron, manganese and nickel. Paste pH was determined before beginning of the first leach.

Chromium, nickel, and iron were analyzed because concentrations in excess of their respective World Bank discharge guidelines were noted during the initial PDM leach testing. Leachate pH was determined to provide a better understanding of the processes governing release of nickel and chromium. Iron was also analyzed since iron hydroxides likely play a major role in the mobility and attenuation of nickel and chromium. Manganese was selected because

analysis of manganese assists in further evaluation of the mobilization mechanisms for nickel and chromium.

As with all laboratory testing, leach procedures are limited in their ability to simulate natural conditions and should be regarded as a semi-quantitative measure of leachate quality. Testing parameters such as the nature of the synthetic leachant, grain size distribution of the sample, and solid-to-solution ratio all affect the outcome of the leach testing. Duplication of on-site conditions is virtually impossible to achieve during laboratory testing. In addition, static leach tests generally are not capable of predicting long-term water quality because its duration is not sufficient to monitor transient chemical reactions such as oxidation of reactive sulphides. Therefore, the leach tests included in the geochemical characterization program represent a qualitative or semi-quantitative estimate of leachate quality that is generally considered useful for identification of constituents of potential environmental concern.

Static leach test results can also be applicable to the qualitative prediction of surface runoff quality. For runoff, the equilibrium conditions inherent to the test are not likely to be representative of those in the field. This is because, in general, the water/rock contact time under ambient conditions will not be sufficiently long to attain equilibrium. Metals concentrations in leach extracts, therefore, may be higher than those occurring in surface runoff.

3 RESULTS

3.1 GEOLOGY

3.1.1 Mine

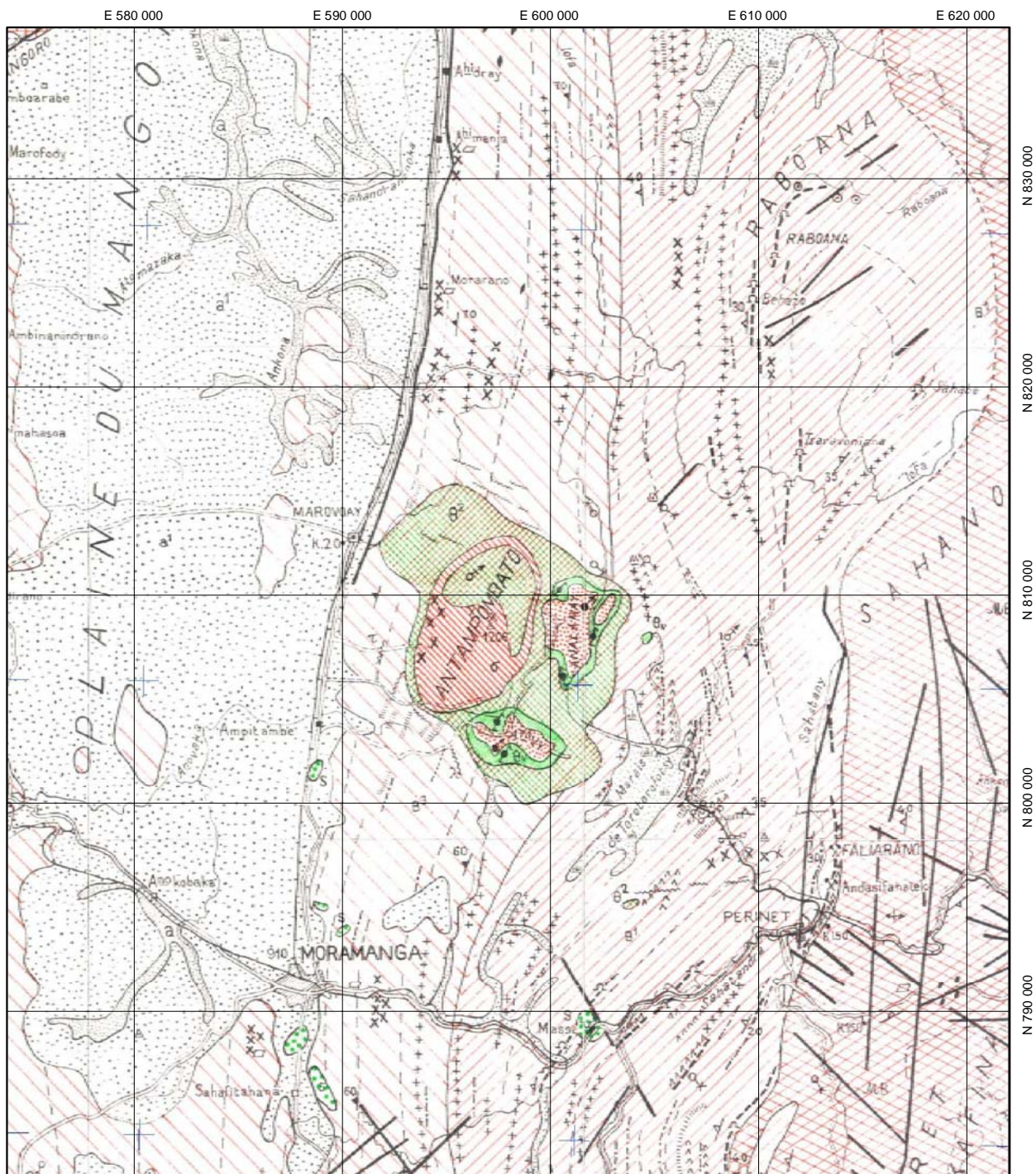
The geology of the project region is documented in the Atlas of Madagascar (1969), Jolly et al. (1984), and Besaire (1967). The regional geology includes Precambrian-aged (4.5 billion years ago to 570 million years ago) metamorphic rocks and Palaeozoic to Tertiary-aged (570 to 2 million years ago) intrusive rocks.

The Precambrian Basement Rocks (metamorphic and igneous) are a broad category of ancient, mainly metamorphic rocks, including all crystalline rocks such as granites, migmatites and schists. They are dated from 3 billion to 550 million years old and form the core of the island of Madagascar. A thick blanket of lateritic clays covers large areas of these rocks. These rocks are mainly exposed on the steeper slopes of the eastern escarpment and as cliffs and granitic inselbergs (an isolated rocky hill rising abruptly from a flat plain) in the central highlands.

Intrusive rocks of the ore bodies are from the Cretaceous Period (136 to 65 million years ago). An intrusive rock is one which, while in a molten fluid state, penetrated into or between other rocks, but solidified before reaching the surface (American Geological Institute 1984). Metamorphic rocks include those which have formed from pre-existing rocks by mineralogical, chemical and structural changes due to temperature, pressure and chemical changes at depth in the earth's crust. These rocks have been influenced by a regional extensional fault system (caused by rock masses spreading apart or put into tension). This movement has created north-south trending extensional faults that bound large blocks of rock. These blocks are termed horsts or grabens, depending on whether they are higher or lower, respectively, than neighbouring rocks.

The dominant feature of the regional geological setting of the project is a north-south striking belt of gneisses and migmatites (Figure 2.1-1). These rocks form part of the high-grade metamorphic rocks that underlie the eastern two-thirds of Madagascar. A large intrusive, known as the Antampombato Complex, believed to be of Cretaceous age, cuts the gneissic terrain, and dominates the geological setting of the project.

R:\CAD\2003\1322-1322-172\6000\6020\Fig2.1-1_Regional_Geology.dwg Feb 13, 2006 - 9:43am



Legend:

- Aluvial
- Silica sands
- Lake Deposit (clay-sand)
- Ferrocrite
- ANTAMPOMATO COMPLEX**
- Syenite
- Gabbro
- Peridotite

SPECIAL PETROGRAPHIC FACIES

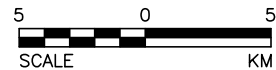
- Quartzites
- Ultrabasic
- Quartzites with magnetite
- Charnockites

ANCIENT BASEMENT

- Granite migmatite
- Syenite with corundum
- Brickville migmatites with amphibole and garnet
- Granite foliated
- Yohimbry System**
- Ancient gabbro

GRAPHITE SYSTEM

- Migmatites of Mangoro (quartzitic-feldspathic)
- MANAMPOSTY GROUP**
- Migmatites and Gneiss with graphite
- Gneiss with pyroxene



REFERENCE

ORIGINAL DRAWING PROVIDED BY DYNATEC CORPORATION.
AMBATOVY NICKEL PROJECT, MORAMANGA AREA, MADAGASCAR.

PROJECT

AMBATOVY PROJECT

TITLE

MINE SITE REGIONAL GEOLOGY MAP



PROJECT 03-1322-172.6000	FILE No.	Fig2.1-1_Reg_Geol
DESIGN GJ 23/06/05	SCALE	AS SHOWN
CADD VR 27/06/05	REV.	0
CHECK GJ 13/02/06	FIGURE: 2.1-1	
REVIEW DM 13/02/06		

The complex occurs on the remnants of a plateau known as the Antampombato Massif. This plateau, a horst structure, is flanked on the east and west by two graben structures. The plateau occurs at an approximate elevation of 1,100 metres above sea level (masl) while the graben structures, represented by basins, occur at elevations of about 900 m. The grabens are filled with 40 to 70 m of recent alluvial sediments. The basin to the west occupies the broad alluvial plain of the Mangoro River, while the basin to the east is represented by the Torotorofotsy Wetlands.

The Antampombato Complex intrusive is elliptical in shape and oriented northwest-southeast with the main axis some 12 km in length and the shorter axis about 7 km in length. The complex is composed mainly of gabbroic and syenitic rocks, and two smaller ultrabasic bodies (Figure 2.1-2). The most significant ultrabasic formations in the country are those in the mine site. This area is an outcrop of nickel-rich ultrabasics. Towards the southern margin of the complex, a lateritic nickel deposit known as the Ambatovy deposit occurs over an ultrabasic body, about 3 by 2.4 km oriented WNW-ESE. The second ultrabasic deposit located at the eastern margin of the complex occurs over an ultrabasic body about 4 by 2.8 km oriented north-south.

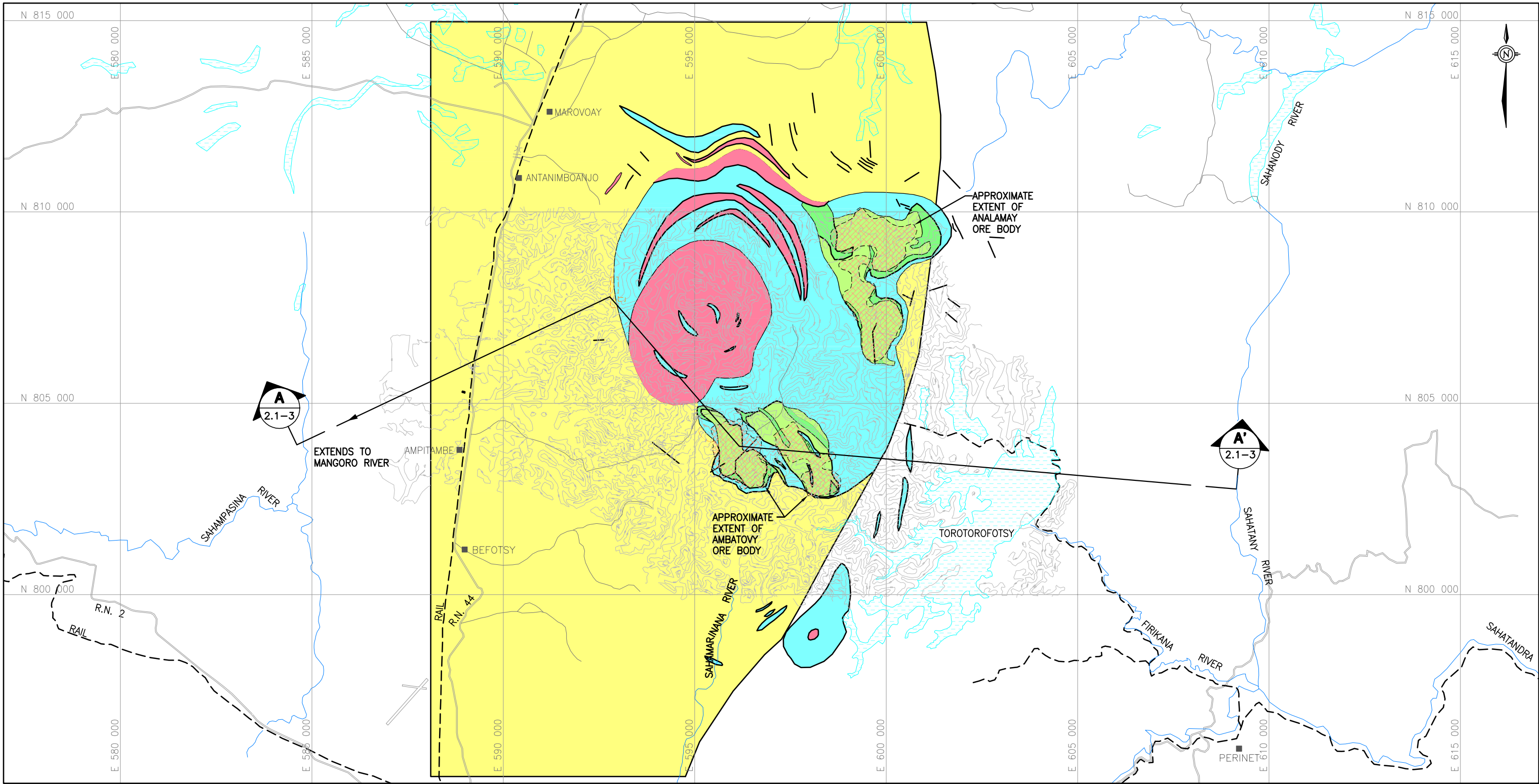
Additional details for geology of the ore bodies and areas just to the east and west are provided below. A cross-section of the geological formations through these areas is shown in Figure 2.1-3.

3.1.1.1 Geology West of Ore Bodies

The geology just west of the ore bodies includes metamorphic rock that has been intruded by dikes of various compositions. A dike is a tabular body of intrusive rock that cuts across the structure of adjacent rocks. Above the metamorphic rock and intrusive bodies is a thick weathered sequence layer, termed laterite. Results of a bedrock drilling program have suggested that, at depth, the contacts between the intrusive dikes and the adjacent materials are not highly fractured zones.

The hills west of the ore bodies site are blanketed by laterite. The laterite is similar in appearance and method of formation to hills around the ore bodies. The laterite profile to the west differs from the ore body profile in several ways due to the differences in the original rock type. The lateritic profile to the west can be subdivided into clayey saprolite and sandy saprolite zones. The clayey saprolite zone is a reddish-brown clay-rich layer up to 50 m in thickness that is similar to the ferrallite zone at the ore body, but is termed saprolite due to the presence of residual quartz. The sandy saprolite is comprised of quartz, mica and feldspar and is nearly uniform in thickness (1 to 3 m).

R:\CAD\2003\1322\03-1322-172\6000\6020\Fig21-2_Loc_Geolgy.DWG Feb 13, 2006 - 9:47am



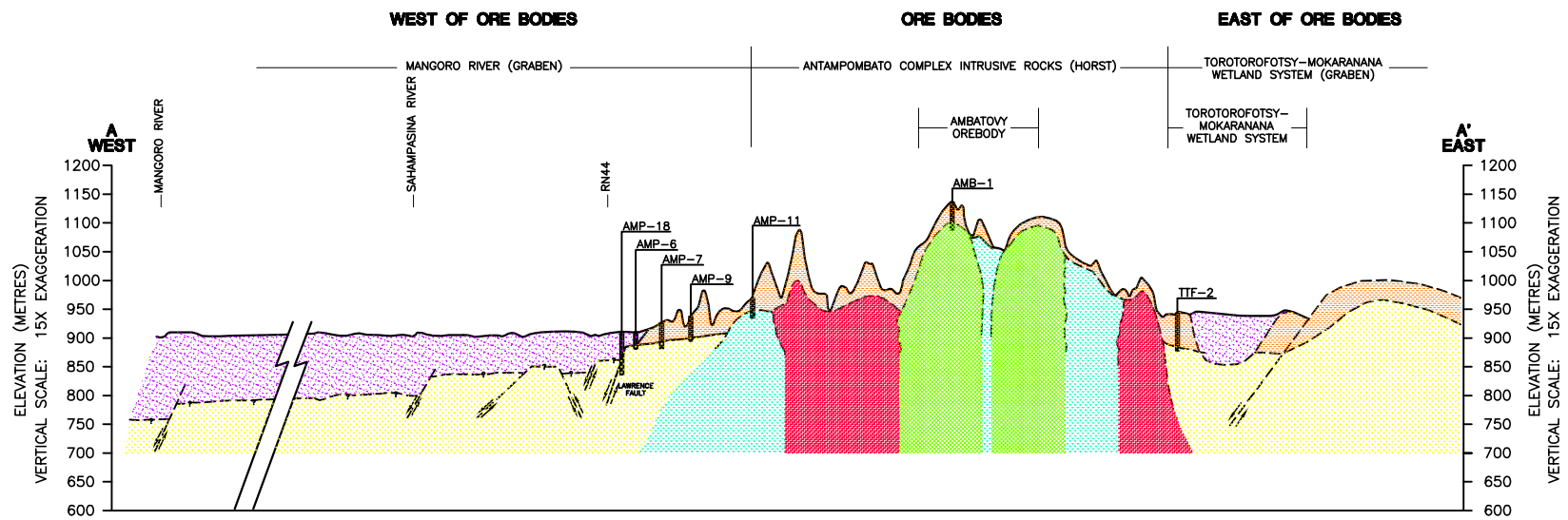
LEGEND

	MAIN ROADS		GABBRO		ANALAMAY AND AMBATOVY ORE BODIES
	RAILROADS		MIGMATITE		GEOLOGIC CROSS SECTION DESIGNATION
	RIVERS		PERIDOTITE		GEOLOGIC CROSS SECTION FIGURE LOCATION
	WETLANDS		PYROXENITE		
	VILLAGES		SYENITE		
	DIKES				

REFERENCE

ORIGINAL DRAWING PROVIDED BY HA SIMONS LTD, 1998.

PROJECT					
AMBATOVY PROJECT					
TITLE					
MINE SITE LOCAL GEOLOGY MAP					
PROJECT 03-1322-172.6000 FILE No. Fig21-2_Loc_Geol					
DESIGN	GJ	23/06/05	SCALE	AS SHOWN	REV. 0
CADD	HL	20/09/05			
CHECK	GJ	13/02/06			
REVIEW	DM	13/02/06			
FIGURE:					2.1-2



A **GEOLOGIC CROSS SECTION A-A'**


250 0 250
SCALE METRES
VERTICAL SCALE: 15X EXAGGERATION

LEGEND

- ALLUVIUM
- LATERITE *
- MELANOCRATIC GABBRO
- MIGMATITE
- PERIDOTITE
- SYENITE
- AMP-7
AMB-1
TTF-2 WELLS
- INFERRED LINEMENT
- LATERITE INCLUDES THE FERRICRETE, FERRALITE AND SAPROLITE ZONES

NOTES

1. ELEVATION SITED TO THE NEAREST 0.10 m
2. CROSS SECTION LOCATION SHOWN AS A - A' ON FIGURE 2.1-2

PROJECT					
AMBATOVY PROJECT					
TITLE					
PROJECT AREA GEOLOGIC CROSS SECTION A					
 Golder Associates Calgary, Alberta		PROJECT 03-1322-172.6000		FILE No. 2.1-3 Tomasina Map	
		DESIGN	GJ	23/06/05	SCALE AS SHOWN
		CADD	IIL	20/09/05	REV. 0
		CHECK	GJ	13/02/06	FIGURE: 2.1-3
		REVIEW	DM	13/02/06	

3.1.1.2 Geology of the Ore Bodies

The geology of the ore bodies consists of ultrabasic (composed chiefly of dark-coloured iron- and magnesium-rich minerals) intrusive rocks of the Cretaceous-aged Antampombato complex. The ultrabasic rocks of this complex are more concentrated in nickel relative to other rocks. Since the ore bodies are exposed on an uplifted ridgeline, they have been subjected to intense weathering from the tropical conditions present in Madagascar. The resulting laterite layer averages about 50 m in thickness. The laterite can be divided into three zones: ferricrete, ferralite and saprolite.

The ferricrete is a surficial layer that forms a several metre-thick hard, rock-like crust over the top of the deposit. The hard ferricrete crust forms as elements dissolve, then precipitate and form more chemically stable minerals during wetting and drying cycles. Beneath the ferricrete lies the ferralite, which is a reddish-brown clay-like layer comprising the bulk of the economic ore. This layer averages 40 m in thickness. The ferralite is considered the primary ore, since it is enriched in nickel and cobalt due to the preferential removal (through natural leaching) of the other elements, in particular magnesium and silicon.

The saprolite layer is the transitional zone where the rock is neither fresh parent material nor is completely altered into the clay-like ferralite. Alteration takes place within this zone along fractures, giving the saprolite an irregular or mottled appearance. These alterations are changes in mineral or chemical composition of the original rock caused by natural interactions with groundwater and/or infiltrating precipitation. Since portions of the parent material are less fractured and have less permeability, these areas remain relatively unaltered within the saprolite and form boulders. The saprolite zone also contains elevated concentrations of nickel and cobalt.

3.1.1.3 Geology East of Ore Bodies

The Torotorofotsy Wetlands lie in a lowland area to the east of the plateau. The geology of this basin is described based on a field investigation completed in the contiguous Mokaranana Wetlands only, and not the entire wetlands system. The geology includes metamorphic rock that has been intruded by dikes of various composition. The intrusive dikes appear to be highly fractured. Above the metamorphic rock and intrusive bodies is a thick saprolite layer, similar to the sequence described for the area west of the ore body.

Alluvial material at the Torotorofotsy-Mokaranana wetlands system is comprised of gravels, sands, silts and clays. The alluvium grades from up to 80 m in thickness along the Mokaranana site southern boundary to a thin veneer in the

northern reaches. The alluvium is thickest along the southern boundary where it also shows a coarser sequence (more coarse sands and gravels than silts and clays). The Torotorofotsy River parallels the southern boundary of the Mokaranana site. It is believed that the river historically meandered across the Mokaranana site's southern boundary, depositing the coarser materials.

3.1.2 Tailings Facility

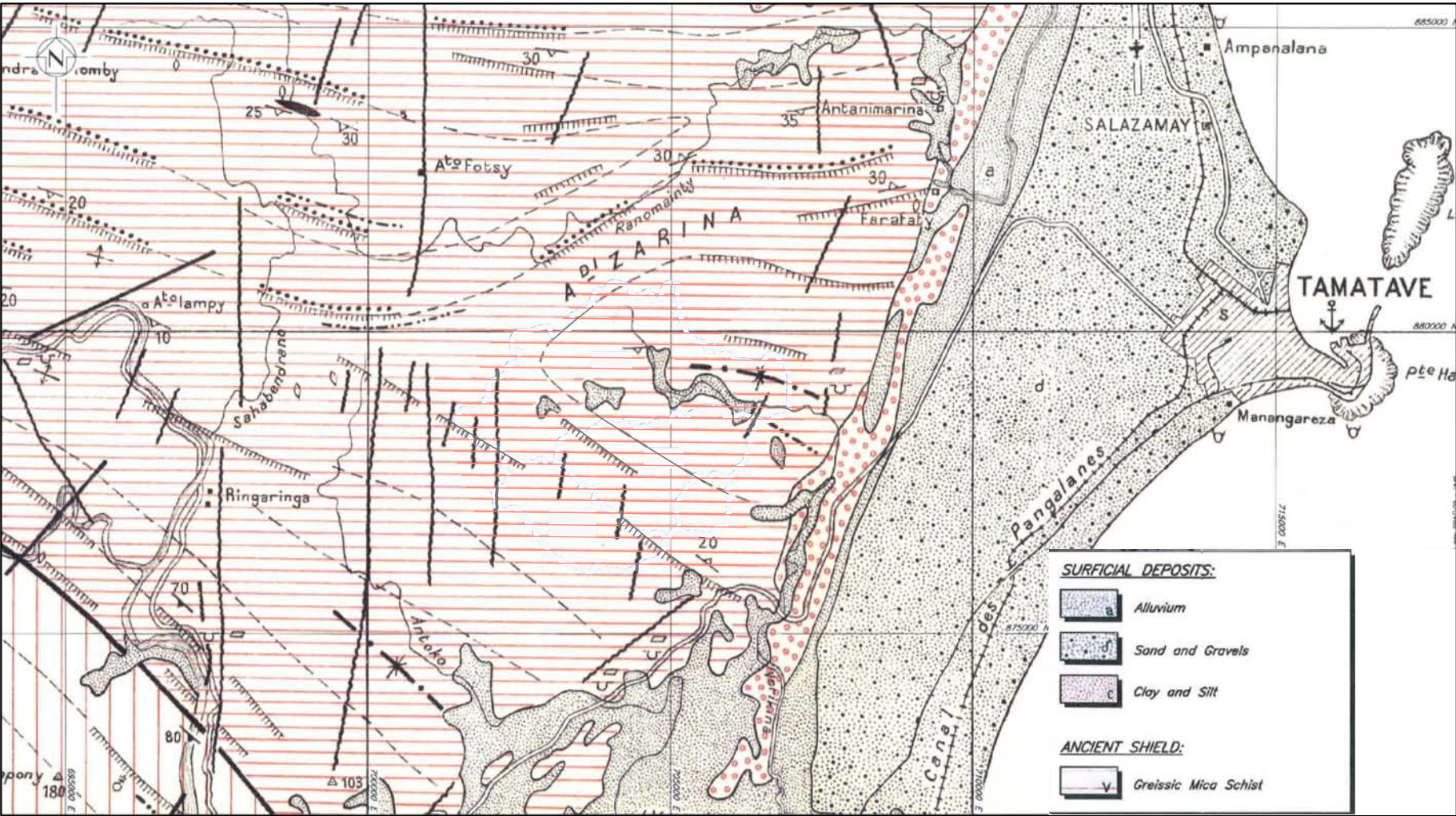
A series of valleys west of Toamasina make up the area of the planned tailings facility. The valleys are located largely within the Vohibory formation consisting of weathered gneissic mica schist (Figure 2.1-4).

The geology of the area is extensively weathered. Highly weathered, sandy silt to silty sand saprolite material was encountered to depths of between 10 and 30 m. Fracturing (semi weathered) was noted below the highly weathered zone. The rock formation seems less weathered and fractured below 40 m.

The main part of the proposed tailings facility is underlain by gneiss, containing biotite and migmatite lenses. Dolerite dykes and sills have intruded the older gneiss rocks. Dykes have a predominantly northeast-southwest to north-south strike direction. The western part of the tailings dam area has been intruded by a large dolerite sill, which is mined for aggregate stone. Alluvium is found along streams and consists of clay, sand, silt and gravel, formed by weathered gneiss, washed from the higher areas. The thickness of this material is thought to be less than 5 m.


3.1.3 Process Plant

The process plant is located on the east coast of Madagascar just south of Toamasina, in an area of flat coastal topography dominated by beach ridges (ridges of marine sedimentary sand deposits extending longitudinally along the coast and originally formed through wave action). A coastal shelf of migmatite material lies below the sandy surficial material.



REFERENCE

ORIGINAL DRAWING PROVIDED BY DYNATEC CORPORATION.
AMBATOVY PROJECT, GEOLOGICAL PLAN OF TAMATAVE AREA.

PROJECT		AMBATOVY PROJECT			
TITLE		TOAMASINA AREA LOCAL GEOLOGY MAP			
 Golder Associates Calgary, Alberta		PROJECT 03-1322-172.6000		FILE No. 2.1-4 Tomasina Map	
		DESIGN	GJ	23/06/05	SCALE AS SHOWN
		CADD	VR	30/06/05	REV. 0
		CHECK	GJ	13/02/06	FIGURE: 2.1-4
		REVIEW	DM	13/02/06	

3.2 GEOCHEMISTRY

3.2.1 Mine Rock and Ore

3.2.1.1 Chemical Composition

The results of the chemical analyses performed on the sixteen mine rock and ore samples are presented in Table 2.1-3. Figure 1 in Volume I-2.1, Attachment 1 presents concentration profiles of three selected major oxides (magnesium oxide, silica oxide, and iron oxide), while Figures 2 and 3 in Volume I-2.1, Attachment 1 present the leachability levels for chromium and nickel, respectively. The concentration profiles were generated using the PDM data set as this constitutes an internally-consistent suite of samples developed specifically for the purpose of evaluating the geochemical characteristics of the entire lithologic sequence.

Table 2.1-3 Chemical Composition

Parameter	Unit	G	FT-Am	FB-Am	FER	NFER	AFER	KAO	LMS-Dy	LMS-PD	Pit 8 SAP	SAP-Dy	SAP-PD	Hard SAP	Bedrock	FT-An	FB-An
Al ₂ O ₃	%	3.37	7.33	6.60	3.78	4.10	15.80	21.3	8.07	6.83	3.68	4.03	3.42	3.86	0.50	5.48	5.14
BaO	%	<0.01	n/a	n/a	0.01	0.02	<0.01	0.02	n/a	0.01	0.02	n/a	<0.01	0.01	<0.01	n/a	n/a
CaO	%	0.01	0.35	0.20	<0.01	0.01	<0.01	0.03	0.24	0.43	1.03	0.38	1.25	1.68	1.33	<0.001	<0.001
Fe ₂ O ₃	%	79	70	69	77	72	56	28	58	33	25	56	22	15	13	70	73
K ₂ O	%	<0.01	n/a	n/a	<0.01	<0.01	0.05	0.24	n/a	0.03	0.07	n/a	0.06	0.14	<0.01	n/a	n/a
MgO	%	0.08	0.27	0.20	0.09	0.42	0.17	0.94	3.90	5.76	18.3	6.5	19.6	30.2	45.5	0.28	0.12
MnO	%	0.17	0.68	1.09	1.03	0.91	1.14	0.57	1.07	0.64	0.42	0.68	0.37	0.20	0.17	1.34	1.59
Na ₂ O	%	<0.05	n/a	n/a	<0.05	<0.05	<0.05	<0.05	n/a	<0.05	0.18	n/a	0.09	0.21	<0.05	n/a	n/a
P ₂ O ₅	%	<0.05	n/a	n/a	<0.05	<0.05	0.08	0.13	n/a	<0.05	<0.05	n/a	<0.05	<0.05	<0.05	n/a	n/a
S	%	0.12	0.23	0.21	0.18	0.15	0.11	0.07	0.14	<0.05	<0.05	0.05	<0.05	<0.05	<0.05	0.25	0.15
SiO ₂	%	1.61	2.33	2.38	1.85	3.11	2.40	26.3	11.9	21.6	33.6	14.6	34.7	42.3	40.9	1.95	1.86
TiO ₂	%	1.49	n/a	n/a	0.35	0.88	3.40	3.25	n/a	1.34	0.58	n/a	0.69	0.66	0.19	n/a	n/a
Ag	mg/kg	n/a	5	<5	n/a	n/a	n/a	n/a	<5	n/a	n/a	<5	n/a	n/a	n/a	n/a	n/a
As	mg/kg	<20	<1	2	<20	<20	<20	<20	4	<20	<20	<1	<20	<20	<20	n/a	n/a
C	mg/kg	n/a	2,300	2,100	n/a	n/a	n/a	n/a	700	n/a	n/a	900	n/a	n/a	n/a	<100	<200
Cd	mg/kg	n/a	<1	<1	n/a	n/a	n/a	n/a	<1	n/a	n/a	<1	n/a	n/a	n/a	n/a	n/a
Cl	mg/kg	n/a	15	18	n/a	n/a	n/a	n/a	10	n/a	n/a	<5	n/a	n/a	n/a	n/a	n/a
Co	mg/kg	168	600	1,190	1,348	928	1,104	423	1,180	676	368	950	351	185	181	1,360	1,590
Cr	mg/kg	12,700	15,800	17,700	11,100	15,800	7,270	6,210	22,200	16,800	8,990	15,400	7,750	3,870	3,290	15,300	27,200
Cu	mg/kg	60	150	180	594	205	376	269	180	123	44	140	88	58	21	120	100
Hg	mg/kg	n/a	<1	<1	n/a	n/a	n/a	n/a	<1	n/a	n/a	<1	n/a	n/a	n/a	n/a	n/a
Li	mg/kg	n/a	<1	<1	n/a	n/a	n/a	n/a	<1	n/a	n/a	<1	n/a	n/a	n/a	n/a	n/a
Mo	mg/kg	<10	n/a	n/a	<10	<10	<10	<10	n/a	<10	<10	n/a	<10	<10	<10	n/a	n/a
Nb	mg/kg	<10	n/a	n/a	<10	<10	36	26	n/a	<10	<10	n/a	<10	<10	<10	n/a	n/a
Ni	mg/kg	3,240	11,200	11,200	6,740	8,770	3,500	4,890	13,200	11,500	22,000	18,800	14,400	7,710	3,040	10,400	10,500
Pd	mg/kg	n/a	<1	<1	n/a	n/a	n/a	n/a	<1	n/a	n/a	<1	n/a	n/a	n/a	n/a	n/a
Pb	mg/kg	13	6	6	15	12	<10	18	8	12	10	6	<10	54	<10	n/a	n/a
Pt	mg/kg	n/a	<1	<1	n/a	n/a	n/a	n/a	<1	n/a	n/a	<1	n/a	n/a	n/a	n/a	n/a
Rb	mg/kg	<10	n/a	n/a	<10	<10	<10	<10	n/a	<10	10	n/a	<10	<10	<10	n/a	n/a
Sb	mg/kg	n/a	<1	<1	n/a	n/a	n/a	n/a	<1	n/a	n/a	<1	n/a	n/a	n/a	n/a	n/a
Sc	mg/kg	n/a	<1	<1	n/a	n/a	n/a	n/a	<1	n/a	n/a	<1	n/a	n/a	n/a	n/a	n/a
Se	mg/kg	n/a	<1	<1	n/a	n/a	n/a	n/a	<1	n/a	n/a	<1	n/a	n/a	n/a	n/a	n/a
Sn	mg/kg	<50	n/a	n/a	<50	<50	68	79	n/a	50	115	n/a	117	151	144	n/a	n/a
Sr	mg/kg	<10	n/a	n/a	<10	<10	12	21	n/a	19	38	n/a	29	56	14	n/a	n/a
Th	mg/kg	64	n/a	n/a	77	55	63	<50	n/a	59	50	n/a	<50	<50	<50	n/a	n/a
U	mg/kg	54	n/a	n/a	<50	54	52	59	n/a	58	62	n/a	51	<50	51	n/a	n/a
V	mg/kg	288	n/a	n/a	145	268	599	581	n/a	266	128	n/a	135	87	25	n/a	n/a
W	mg/kg	<10	n/a	n/a	<10	<10	<10	<10	n/a	<10	<10	n/a	<10	<10	<10	n/a	n/a
Y	mg/kg	<10	n/a	n/a	<10	19	16	36	n/a	34	22	n/a	16	22	<10	n/a	n/a
Zn	mg/kg	148	390	450	178	331	153	215	440	362	179	490	205	102	89	630	700
Zr	mg/kg	75	n/a	n/a	10	29	165	224	n/a	63	64	n/a	35	45	<10	n/a	n/a

The major oxides show concentration gradients that are characteristic of residual nickel deposits. As the degree of lateritization decreases from top to bottom, the iron content decreases as well, whereas the silica and magnesium oxide contents gradually increase to the values of the peridotitic parent material.

Chromium and nickel trends also are typical for lateritic sequences. Chromium in the various rock types is primarily present as the refractory mineral chromite, although in the upper portions of the profile a significant portion of the chromium occurs in more labile form associated with the limonite (a generic term used in residual deposits for iron (hydr)oxides such as goethite, magnetite and hematite/maghemite). The nickel trend is similar, increasing from the ferricrete to the Pit 8 saprolite, after which its concentration declines. Nickel in the weathered parts of the profile also occurs associated with limonite, whereas in the saprolite/bedrock, nickel is thought to be incorporated primarily in amorphous hydrosilicates such as garnierite.

The chemical compositions of the four Dynatec Ambatovy samples generally are similar to their closest analogues in the PDM data set. The Analamay samples are similar to their Amabatovy equivalents, with the exception of a lower carbon content and higher cobalt and zinc content. As stated above, the PDM program did not include any samples from the Analamay deposit.

3.2.1.2 Mineralogical Composition

Results from the x-ray diffraction (XRD) analysis (Table 2.1-4) confirm the previous findings that the majority of minerals present in the stratigraphic sequence of the Ambatovy ore deposit are oxides and hydroxides. The ferricrete, ferralite and bauxite exclusively consist of these compounds. Most abundant are the iron (hydr)oxides goethite [FeOOH], magnetite [Fe₃O₄], and hematite/maghemite [α -Fe₂O₃/ γ -Fe₂O₃]. Gibbsite [Al(OH)₃] also is encountered in most samples.

Goethite is the major constituent in the ferricrete, ferralite, bauxite and low-magnesium saprolite. Silicates are primarily found in the saprolite and bedrock samples. In the saprolite, clay minerals (kaolinite, smectite), quartz and sheet silicates (clinochrysotile, clinocllore, and talc) are observed. Forsterite (magnesium-olivine) is the major constituent of the peridotite bedrock. All minerals identified are typical of the weathering profile and various stratigraphic units in nickel laterite deposits.

No mineralogical analysis was conducted on the two Analamay samples. However, based on their chemical similarity and formation (i.e., by weathering) from similar ultrabasic parent material, the mineralogy of the Analamay ore is assumed to be similar to that of Ambatovy. This was confirmed by three recent XRD spectograms (Volume I-2.1, Attachment 2).

Table 2.1-4 Mineralogical Composition

Mineral	Formula	G	FT-Am	FB-Am	FER	NFER	AFER	KAO	LMS-Dy	LMS-PD	Pit 8 SAP	SAP-Dy	SAP-PD	Hard SAP	Bedrock
Goethite	FeOOH	major	major	major	major	major	major	subordinate	major	major	minor	major	minor		
Magnetite	Fe ₃ O ₄				minor	minor	minor-sub	subordinate		minor	major		minor		trace-minor
Hematite/Maghemite	α-Fe ₂ O ₃ /γ-Fe ₂ O ₃	subordinate	minor	minor		possible minor	minor-sub		minor			minor			trace
Gibbsite	Al(OH) ₃	trace	minor	minor		minor	subordinate	minor	minor	trace		minor			
Quartz	SiO ₂								trace			trace			
Forsterite	Mg ₂ SiO ₄										trace		minor	major	major
Smectite	possibly saponite												minor	minor	
Clinochlore	Mg ₅ Al(Si ₃ Al)O ₁₀ (OH) ₈									trace	trace		minor	minor	
Kaolinite	Al ₂ Si ₂ O ₅ (OH) ₄							major		trace			possible minor		
Clinochrysotile	Mg ₃ Si ₂ O ₅ (OH) ₄										minor		subordinate	minor	minor
Tremolite	Ca ₂ (Mg,Fe) ₅ Si ₈ O ₂₂ (OH) ₂									subordinate	subordinate		subordinate	subordinate	
Talc	Mg ₃ Si ₄ O ₁₀ (OH) ₂									trace	trace	trace	trace-minor	minor	

Relative abundance terminology:
Major - Most abundant species, but may be less than 50% if several other subordinate species are present.
Subordinate - Relatively abundant, but less than the major species.
Minor Subordinate - Intermediate between minor and subordinate.
Minor - Less abundant species, typically less than 10% of total.
Trace - Detected, but at low concentration, typically less than 5%.

3.2.1.3 Acid-Base Accounting

The ABA and paste pH results for the ore and mine rock are summarized in Table 2.1-5. The sulphur contents of all samples are very low (less than 0.2 wt% as total sulphur). Sulphide sulphur is at or below its detection limit of 0.1 wt%. Values for paste pH range from slightly acidic (5.7 for the most surficial sample) to alkaline (9.4 for the bedrock). Both the ANP and paste pH values increase with depth due to the increasing content of alkaline, magnesium-rich minerals with depth.

For all samples, the sulphide sulphur content was at or below the method detection limit of 0.01 wt%. For sulphide sulphur levels this low, a material is generally considered non-acid-generating as sufficient reactive sulphur is not present for development of acidic conditions. In Price (1997), an ARD screening criterion is presented for such low-sulphide materials: if the sulphide sulphur content is less than 0.3% and the paste pH is greater than 5.5, the material is considered non-acid-generating and no further ARD testing is required. Exceptions are where the rock matrix consists entirely of base-poor minerals (such as quartz) or where metal leaching may still be a concern.

Figure 4 in Volume I-2.1, Attachment 1 shows the relationship between sulphide sulphur content and paste pH. All samples meet the Price screening criteria of sulphide sulphur < 0.3 wt% and paste pH > 5.5. In fact, since all total sulphur contents are below 0.3 wt% as well, even if total sulphur were used instead of sulphide sulphur, the samples would be considered non-acid-generating.

The potential of a geologic material to generate acid rock drainage (ARD) can be further described by comparing the amount of neutralizing capacity, expressed as ANP, to the amount of acid-generation capacity, expressed as AGP, present in the rock. In general, the neutralizing capacity is represented by the carbonate minerals present, whereas the acid-generation capacity is represented by reactive sulphide minerals. The ratio of these two parameters, referred to as the neutralization potential ratio (NPR), was calculated for each of the sixteen samples, based on the results of the ABA tests.

The NPR values were then compared to the B.C. (Canada) Ministry of Employment and Investment guidelines outlined in Draft Guidelines and Recommended Methods for the Prediction of Metal Leaching and Acid Rock Drainage at Minesites in British Columbia (Price, 1997). These guidelines are presented in Table 2.1-6. In the absence of formal Malagasy or international standards for assessment of ARD potential, the B.C. Guidelines have found widespread regulatory and industry acceptance, and represent the most commonly used set of criteria for interpretation of ABA results.

Table 2.1-5 Acid-Base Accounting (Mine)

Parameter	Unit	G	FT-Am	FB-Am	FER	NFER	AFER	KAO	LMS-Dy	LMS-PDM	Pit 8 SAP	SAP-Dy	SAP-PDM	Hard SAP	Bedrock	FT-An	FB-An
paste pH	s.u.	5.66	6.16	6.13	6.23	6.36	6.54	6.03	6.83	6.44	7.61	7.17	7.50	8.82	9.41	5.97	6.07
total sulphur ^(a)	wt%	0.03	0.17	0.15	0.01	0.11	0.01	0.01	0.10	0.05	0.10	0.03	0.16	0.19	0.01	0.10	0.17
sulfide sulphur ^(a)	wt%	0.01	< 0.01	< 0.01	0.01	< 0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
sulfate sulphur ^(a)	wt%	< 0.01	0.16	0.14	< 0.01	< 0.01	< 0.01	< 0.01	0.09	< 0.01	0.02	0.03	0.03	0.07	< 0.01	0.10	0.17
non-extractable sulphur ^(a)	wt%	0.03	< 0.01	< 0.01	< 0.01	0.14	< 0.01	0.02	< 0.01	0.06	0.09	< 0.01	0.15	0.19	< 0.01	< 0.01	< 0.01
total carbon	wt%	n/a	0.19	0.20	n/a	n/a	n/a	n/a	0.07	n/a	n/a	0.10	n/a	n/a	n/a	0.11	0.09
inorganic carbon	wt%	n/a	0.02	0.03	n/a	n/a	n/a	n/a	0.02	n/a	n/a	0.03	n/a	n/a	n/a	< 0.01	0.02
acid-neutralization potential (ANP) ^(a)	kg CaCO ₃ /ton	1.7	2.7	1.7	< 0.01	1.0	0.8	0.9	8.6	9.8	29.4	15.9	38.7	49.6	97.4	2.8	1.7
acid-generation potential (AGP) ^(b)	kg CaCO ₃ /ton	0.3	< 0.3	< 0.3	0.3	< 0.3	0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
net neutralization potential (NNP) ^(c)	kg CaCO ₃ /ton	1.4	2.4	1.4	-0.3	0.7	0.5	0.6	8.3	9.5	29.1	15.6	38.4	49.3	97.1	2.5	1.4
neutralization potential ratio (NPR) ^(c)		5.4	> 8.6	> 5.4	0.0	> 3.2	2.6	> 2.9	> 28	> 31	> 94	> 51	> 124	> 159	> 312	> 9.0	> 5.4

^(a) The neutralization potential and sulphur forms are averages from triplicate analyses (PDM samples only).

^(b) AGP and NPR were derived using pyritic sulphur.

^(c) NNP and NPR were calculated using the detection limit of pyritic sulphur.

n/a Not applicable.

Table 2.1-6 Acid Rock Drainage Screening Criteria (Price, 1997)

Potential for ARD	Initial Screening Criteria	Comments
likely	NPR <1	likely acid-generating, unless sulphide minerals are non-reactive
possible (uncertain)	1<NPR<2	possibly acid-generating if NP is insufficiently reactive or is depleted at a rate faster than sulphides
low	NPR 2-4	not potentially acid-generating unless significant preferential exposure of sulphides along fractures planes, or extremely reactive sulphides in combination with insufficiently reactive NP
none	NPR >4	

NPR = Neutralization potential ratio.

Based on the NPR values for the 16 samples, one sample (FER) would be classified as likely acid-generating, three samples (NFER, AFER, KAO) would be classified as having a low potential for acid generation, and the remainder would be considered non-acid-generating. However, as discussed previously, even for the samples with NPR values indicative of ARD potential, the amount of sulphide present is insufficient for acid generation.

Based on this evidence, acid generation through sulphide oxidation is not considered feasible, and the various lithologic materials at the Ambatovy and Analamay ore bodies are classified as non-acid-generating. Therefore, additional kinetic testing to further evaluate the acid generation potential is not considered necessary. In fact, some of the materials (saprolite, bedrock) contain considerable excess neutralization potential. However, it should be noted that generation of slightly acidic, metal-rich leachates can still occur from the shallower materials (ferricrete, ferralite, bauxite, clay) due to the presence of soluble metal (hydr)oxides. The leachability of the various ore types is discussed in more detail in the following sections.

3.2.1.4 Entrained Water Quality

Analytical results for entrained water in four Dynatec Ambatovy samples are presented in Table 2.1-7. This table also presents the applicable Malagasy and World Bank standards for effluents. Values in excess of these standards are indicated by shaded cells. The determination of chromium speciation is a difficult challenge due to the issues of field sample preservation and promptness of analysis. For the sake of conservativeness, the chromium is measured as total chromium and assumed to be all in the hexavalent state. Work conducted to date has shown that both trivalent and hexavalent chromium species exist, however, their ratio could not be clearly defined.

Table 2.1-7 Entrained Water Quality

Parameter	Unit	Madagascar/World Bank Effluent Limits	FT-Am	FB-Am	LMS-Dy	SAP-Dy
pH	s.u.	6.0 - 9.0	6.62	7.30	7.43	7.40
Ag	mg/L		<0.005	<0.005	<0.005	<0.005
Al	mg/L	5.0	0.027	<0.003	<0.003	<0.003
As	mg/L	0.1	<0.03	<0.03	<0.03	<0.03
B	mg/L		<0.005	<0.005	<0.005	0.040
C total	mg/L		19	42	57	21
C organic	mg/L		19	42	57	21
Cd	mg/L	0.02	<0.002	<0.002	0.0070	0.0074
Cl	mg/L		9.8	n/a	10.9	7.8
Co	mg/L		<0.004	<0.004	0.140	0.139
Cr	mg/L	0.5 / 0.05 ¹	<0.003	0.030	0.766	1.36
Cu	mg/L	0.3	<0.001	<0.001	<0.001	<0.001
F	mg/L		<0.1	<0.1	<0.1	<0.1
Fe	mg/L	2	<0.003	<0.003	0.130	0.127
Mg	mg/L		3.78	5.90	18.5	18.3
Mn	mg/L	5.0	0.019	<0.001	0.014	<0.005
Mo	mg/L		<0.005	<0.005	0.011	0.019
Na	mg/L		6.92	8.62	6.63	5.82
Ni	mg/L	0.5	0.041	0.026	0.263	0.252
P	mg/L		<0.03	<0.03	<0.03	<0.03
Pb	mg/L	0.2	<0.01	<0.01	<0.01	<0.01
S	mg/L		11.7	25.1	27.0	25.1
Th	mg/L		<0.04	<0.04	<0.04	<0.04
Zn	mg/L	0.5	<0.002	<0.002	0.016	<0.006

^(a) Total chromium / hexavalent chromium.

n/a = Not applicable.

The entrained water is circum-neutral (pH between 6.6 and 7.4) with generally very low trace metal concentrations. Water quality criteria are met for almost all parameters, except for chromium in samples LMS-Dy and SAP-Dy. These results generally are in good agreement with those from the SPLP testing, as discussed in the next section.

3.2.1.5 Synthetic Precipitation Leaching Procedure Results

As part of this study, an initial round of single-stage SPLP tests was conducted on the ten composite samples obtained from the Ambatovy ore body. These initial tests were followed by three consecutive SPLP tests performed on fresh splits of the same samples to assess the potential longer-term leachability of these

materials. The SPLP results were described and interpreted by two methods: (1) examination of the concentrations of a solute in the SPLP leachate, and (2) comparison between the total amount of solute released and the solid-phase concentration of that constituent to determine relative leachability.

Tables 2.1-8 and 2.1-9 present the results from the single-stage and sequential SPLP testing, respectively. Values in excess of effluent criteria are highlighted.

Figures 2, 3 and 5 in Volume I-2.1, Attachment 1 show concentration and SPLP leachability profiles for chromium, nickel and iron, respectively, from the PDM investigation. These three parameters were selected for detailed evaluation as they demonstrate the greatest number of values in excess of the effluent standards. Included are the chromium, nickel, and iron (as iron oxide) contents of the rock samples, the total chromium, nickel and iron concentrations in the leachates, and the percentages leached during the single-stage SPLP tests.

Figures 6 through 9 in Volume I-2.1, Attachment 1 present a comparison of leachability between analogous samples from the PDM and Dynatec characterization efforts. Results are shown for pH, chromium, nickel and iron, with the various samples divided over three categories: ferralite, low-magnesium saprolite and saprolite.

Figures 10 through 13 in Volume I-2.1, Attachment 1 show a comparison between single-stage SPLP results and entrained water quality for pH, chromium, nickel and iron.

The results from the consecutive SPLP tests are presented in Figures 14 through 17 in Volume I-2.1, Attachment 1. Results from the initial, single-stage SPLP test are designated as SPLP-0; results from the sequential, three-step SPLP testing are designated as SPLP-1, SPLP-2, and SPLP-3, respectively.

Table 2.1-8 Single-Stage Synthetic Precipitation Leaching Procedure Results

		Madagascar/World Bank Effluent Limits	G	FT-Am	FB-Am	FER	NFER	AFER	KAO	LMS-Dy	LMS-PD	Pit 8 SAP	SAP-Dy	SAP-PD	Hard SAP	Bedrock	FT-An	FB-An
pH	s.u.	6.0 - 9.0	6.55	6.59	7.27	6.15	6.20	6.47	6.20	6.98	6.63	7.74	6.71	7.57	7.90	9.75	6.74	6.69
Alkalinity	mg/L as CaCO ₃		n/a	6	3	n/a	n/a	n/a	n/a	4	n/a	n/a	4	n/a	n/a	n/a	2	2
Conductivity	µS/cm	200	n/a	36	28	n/a	n/a	n/a	n/a	90	n/a	n/a	71	n/a	n/a	n/a	26	28
Ag	mg/L		0.0026	< 0.0001	< 0.0001	< 0.0002	< 0.0002	0.0270	0.0055	< 0.0001	0.0009	< 0.0002	< 0.0001	< 0.0002	< 0.0002	< 0.0002	< 0.0001	< 0.0001
Al	mg/L	5.0	< 0.05	0.009	0.010	< 0.05	< 0.05	< 0.05	< 0.05	0.023	< 0.05	1.57	0.008	0.57	3.99	< 0.05	0.015	< 0.004
As	mg/L	0.1	0.002	< 0.005	< 0.005	0.003	0.002	0.001	0.002	< 0.005	< 0.001	0.002	< 0.005	< 0.001	0.002	0.002	< 0.005	< 0.005
Ba	mg/L		< 0.04	0.320	0.286	< 0.04	< 0.04	< 0.04	< 0.04	0.071	< 0.04	0.18	0.069	0.12	0.16	< 0.04	0.255	0.169
Ca	mg/L		3.12	0.84	1.02	0.22	0.17	0.26	0.04	0.80	0.12	1.27	0.65	0.61	0.77	3.67	1.15	1.81
Cd	mg/L	0.02	< 0.001	< 0.0005	< 0.0005	< 0.001	< 0.001	< 0.001	< 0.001	< 0.0005	< 0.001	< 0.001	< 0.0005	< 0.001	< 0.001	< 0.001	< 0.0005	< 0.0005
Cl	mg/L		1.7	n/a	n/a	2.3	2.2	1.4	0.9	n/a	0.9	1.3	n/a	1.9	1.0	1.9	n/a	n/a
Co	mg/L		< 0.01	< 0.0003	< 0.0003	< 0.01	< 0.01	< 0.01	< 0.01	< 0.0003	< 0.01	< 0.01	< 0.0003	< 0.01	< 0.01	< 0.01	< 0.0003	< 0.0003
Cr	mg/L	0.5 / 0.05 ^(a)	0.01	0.015	0.030	0.13	0.04	0.07	0.37	0.850	0.33	3.00	1.45	1.26	0.24	0.01	0.123	0.603
Cu	mg/L	0.3	< 0.01	< 0.0008	< 0.0008	0.03	0.01	< 0.01	0.01	0.0010	0.02	0.01	< 0.0008	< 0.01	0.03	< 0.01	< 0.0008	< 0.0008
F	mg/L		< 0.05	0.09	0.08	0.06	0.05	0.05	< 0.05	< 0.06	< 0.05	0.14	< 0.06	0.19	0.20	0.09	0.08	< 0.06
Fe	mg/L	2	0.02	0.02	0.05	0.02	0.01	0.07	< 0.01	0.22	0.04	8.41	< 0.02	3.34	18.6	0.02	0.06	0.03
Hg	µg/L	2	< 0.1	< 0.1	< 0.1	0.1	< 0.1	0.2	0.1	< 0.1	< 0.1	0.1	< 0.1	< 0.1	0.1	< 0.1	< 0.1	< 0.1
K	mg/L		0.28	0.14	0.04	0.96	0.13	0.08	< 0.02	0.05	< 0.02	0.11	0.08	0.27	< 0.02	< 0.02	0.04	0.04
Mg	mg/L		1.73	0.198	0.336	1.60	0.50	0.73	0.49	8.49	0.90	16.8	5.99	7.11	20.3	4.70	0.350	0.657
Mn	mg/L	5.0	0.13	0.0068	0.0058	0.03	0.03	0.03	0.03	0.0023	0.01	0.10	< 0.0007	0.06	0.22	0.01	0.0042	0.0024
Mo	mg/L		< 0.01	n/a	n/a	0.03	0.02	0.02	< 0.01	n/a	< 0.01	< 0.01	n/a	0.02	< 0.01	< 0.01	n/a	n/a
Na	mg/L		5.07	6.51	2.49	4.77	3.57	2.72	1.97	1.44	2.82	4.71	1.46	3.23	2.34	< 0.02	2.28	1.61
NH ₃	mg/L as N	15	0.86	n/a	n/a	0.67	0.37	0.21	0.12	n/a	0.05	0.16	n/a	0.04	< 0.02	< 0.02	n/a	n/a
Ni	mg/L	0.5	0.02	0.002	0.003	0.05	0.03	0.04	0.02	0.002	0.08	2.63	0.007	1.10	3.25	0.02	0.006	0.002
NO ₂	mg/L as N	0.2	0.02	< 0.6	< 0.6	0.10	0.07	0.09	0.08	< 0.6	0.09	0.05	< 0.6	0.03	0.02	0.03	< 0.6	< 0.6
NO ₃	mg/L as N	20	0.46	n/a	n/a	0.45	0.48	0.39	0.23	n/a	0.29	0.44	n/a	0.70	< 0.12	< 0.12	n/a	n/a
P	mg/L		0.002	< 0.1	< 0.1	< 0.001	< 0.001	0.002	< 0.001	< 0.1	0.015	< 0.001	< 0.1	< 0.001	< 0.001	< 0.001	< 0.1	< 0.1
Pb	mg/L	0.2	< 0.001	< 0.0002	< 0.0002	0.001	< 0.001	< 0.001	< 0.001	< 0.0002	< 0.001	< 0.001	< 0.0002	< 0.001	0.007	< 0.001	< 0.0002	< 0.0002
Sb	mg/L		< 0.005	n/a	n/a	< 0.005	< 0.005	< 0.005	< 0.005	n/a	< 0.005	< 0.005	n/a	< 0.005	< 0.005	< 0.005	n/a	n/a
Se	mg/L	0.02	< 0.005	n/a	n/a	< 0.005	< 0.005	< 0.005	< 0.005	n/a	< 0.005	< 0.005	n/a	< 0.005	< 0.005	< 0.005	n/a	n/a
Si	mg/L		n/a	0.06	0.08	n/a	n/a	n/a	n/a	0.28	n/a	n/a	0.57	n/a	n/a	n/a	0.07	0.06
SO ₄	mg/L	250	n/a	n/a	n/a	n/a	n/a	n/a	n/a	32	n/a	n/a	21	n/a	n/a	n/a	n/a	9.4
V	mg/L		< 0.01	< 0.0009	< 0.0009	< 0.01	< 0.01	< 0.01	< 0.01	< 0.0009	< 0.01	< 0.01	< 0.0009	< 0.01	< 0.01	< 0.01	< 0.0009	< 0.0009
Zn	mg/L	0.5	< 0.05	0.021	0.006	< 0.05	< 0.05	< 0.05	< 0.05	0.014	< 0.05	< 0.05	0.067	< 0.05	< 0.05	< 0.05	0.006	0.014

^(a) Total chromium / hexavalent chromium.

n/a = Not available.

Table 2.1-9 Sequential Consecutive Synthetic Precipitation Leaching Procedure Results

Parameter	Unit	Madagascar/World Bank Effluent Limits	G	FER	NFER	AFER	KAO	LMS-PD	Pit 8 SAP	SAP-PD	Hard SAP	Bedrock
First SPLP Leachate (SPLP-1)												
Cr	mg/L	0.5 / 0.05 ^(a)	<0.01	3.86	0.22	0.09	0.89	1.20	0.74	5.72	0.12	< 0.01
Fe	mg/L	2	0.05	0.02	1.95	0.11	< 0.01	0.02	3.57	55.1	0.98	0.02
Mn	mg/L	5.0	0.11	<0.01	0.02	0.04	0.02	<0.01	0.50	0.49	< 0.01	< 0.01
Ni	mg/L	0.5	<0.02	<0.02	0.06	0.04	0.02	<0.02	6.55	16.2	0.16	< 0.02
pH	s.u.	6.0 - 9.0	6.15	7.65	6.28	6.39	6.06	6.89	7.59	8.25	7.46	9.71
Second SPLP Leachate (SPLP-2)												
Cr	mg/L	0.5 / 0.05 ^(a)	<0.01	1.82	0.86	0.16	0.46	0.52	0.43	0.49	0.05	<0.01
Fe	mg/L	2	0.01	<0.01	22.7	0.60	<0.01	<0.01	50.4	2.22	2.78	0.02
Mn	mg/L	5.0	0.23	<0.01	0.22	0.25	0.01	<0.01	0.60	0.01	0.03	<0.01
Ni	mg/L	0.5	0.02	<0.01	0.66	0.14	<0.01	<0.01	8.07	0.59	0.54	<0.01
pH	s.u.	6.0 - 9.0	6.14	6.95	6.54	6.37	6.19	6.54	7.57	7.34	6.99	9.67
Third SPLP Leachate (SPLP-3)												
Cr	mg/L	0.5 / 0.05 ^(a)	0.01	1.28	0.08	0.04	0.33	0.27	0.08	0.38	0.05	<0.01
Fe	mg/L	2	0.01	0.08	0.92	0.55	<0.01	0.56	1.70	15.00	5.26	2.01
Mn	mg/L	5.0	0.37	0.01	3.34	0.35	0.04	0.02	0.04	0.21	0.09	<0.03
Ni	mg/L	0.5	0.06	<0.02	1.10	0.17	0.03	0.10	0.52	3.67	1.06	0.09
pH	s.u.	6.0 - 9.0	6.30	7.21	6.48	6.28	5.96	6.35	7.01	7.01	7.17	9.71
Single-stage SPLP Leachate (SPLP-0)												
Cr	mg/L	0.5 / 0.05 ^(a)	< 0.01	0.13	0.04	0.07	0.37	0.33	3.00	1.26	0.24	< 0.01
Fe	mg/L	2	0.02	0.02	0.01	0.07	< 0.01	0.04	8.41	3.34	18.6	0.02
Mn	mg/L	5.0	0.13	0.03	0.03	0.03	0.03	0.01	0.10	0.06	0.22	< 0.01
Ni	mg/L	0.5	0.02	0.05	0.03	0.04	0.02	0.08	2.63	1.10	3.25	0.02
pH	s.u.	6.0 - 9.0	6.55	6.15	6.20	6.47	6.20	6.63	7.74	7.57	7.90	9.75

^(a) Total chromium / hexavalent chromium.

Leachability Profiles

The SPLP leachates show a pH range between about 6.1 and 9.8, with pH generally increasing with depth. This range is very similar to that for the paste pH (5.7 to 9.4). Chromium, nickel and iron concentrations in the single-stage SPLP leachates generally are lowest in the upper portions of the stratigraphic sequence, and reach maximum values in the saprolite (Figures 2, 3 and 5 in Volume I-2.1, Attachment 1). The relative percentages of chromium, nickel and iron leached follow this trend.

Excellent correlation is found between the SPLP concentrations and the leach percentages, with correlation coefficients of 0.99, 0.90 and 0.98 for chromium, nickel and iron, respectively. This indicates that the saprolite is the most leachable material, both in absolute and relative terms.

Given that the upper materials (ferricrete, ferralite, bauxite and kaolinite clay) are residual materials, formed by extensive tropical weathering and removal of soluble constituents, it is not surprising that their leachability is low. In the weathered saprolite below the lateritic units, chromium, nickel and iron are relatively leachable, whereas in the fresh bedrock their leachability is again minimal. These observations are confirmed by the results from the consecutive SPLP testing.

Comparison Between Dynatec and PDM Samples

The SPLP procedures used for the PDM and Dynatec samples differed with regard to use of the lixiviant. The PDM program applied a leachant with a pH of 4.2, whereas the Dynatec samples were leached with a solution with a pH between 5 and 6, representing the pH of normal precipitation. Figures 6 through 9 in Volume I-2.1, Attachment 1 present a comparison between these two sets of SPLP results for the Ambatovy samples, focusing on pH and leachability of chromium, nickel and iron.

Percent leachability was selected for the comparison as this provides a means of evaluating samples that is independent of differences in initial composition. The samples are divided in three general categories: ferralite (FT-Am, FB-Am, FER, NFER), low-magnesium saprolite (LMS-Dy and LMS-PDM) and saprolite (SAP-Dy and SAP-PDM), separated by vertical bars in the figures.

In general, leachate pH values for the Dynatec samples are higher than those for the PDM samples by about 0.5 to 1 pH unit. This is consistent with the nature of the lixiviants used in the two SPLP programs. However, the two saprolite

samples demonstrate the opposite behavior, with the PDM leachate sample showing a higher pH than the Dynatec sample.

For the ferralite samples, chromium and nickel leachability are enhanced in the low-pH PDM leachates. On the other hand, for iron, the opposite is observed. In leachates from the low-magnesium saprolite samples, iron and chromium show enhanced leachability in the Dynatec sample, with nickel demonstrating opposite behavior. For the saprolite samples, for all three parameters the PDM sample has a higher leachability than the Dynatec sample.

From this small set of results, it is clear that the effect of use of different leachants does not lend itself to straightforward interpretation. Use of a lower-pH lixiviant does not always result in a lower pH of the final SPLP leachate. Similarly, a lower pH does not always result in enhanced leachability, and the three parameters show different behavior in different lithologies despite similarities in geochemical characteristics, in particular between iron and nickel.

Comparison Between Entrained Water Quality and Synthetic Precipitation Leaching Procedure Results

The comparison between entrained water quality and SPLP results for four Dynatec Ambatovy samples is illustrated by Figures 10 through 13 in Volume I-2.1, Attachment 1. Values for pH are slightly higher in the entrained water than in the corresponding leachates. Chromium and iron generally show highest concentrations in the lower-pH SPLP leachates (with the exception of iron in the SAP samples), but nickel shows the opposite trend for all four samples.

As for the comparison presented in the previous section between the Dynatec and PDM SPLP results, the differences in leaching behavior cannot be described in a straightforward manner, as the expected relationships between pH and metal leachability do not always manifest themselves.

Consecutive Synthetic Precipitation Leaching Procedure Tests

Values for pH tend to vary only slightly (i.e., by less than about 0.5 pH unit) over the three consecutive leaches conducted as part of the PDM characterization program (Figure 14 in Volume I-2.1, Attachment 1). Chromium concentrations generally decrease over consecutive SPLP leaches (Figure 15 in Volume I-2.1, Attachment 1). Highest initial concentrations are observed in the saprolite samples and one ferralite sample (NFER). Nickel concentrations in consecutive leachates do not show consistent behavior (Figure 16 in Volume I-2.1,

Attachment 1). For several samples, nickel concentrations in the third leachate are higher than those in first leachates.

Highest leachate concentrations are observed in the saprolite samples. Iron concentrations in successive leachates also show variable trends (Figure 17 in Volume I-2.1, Attachment 1). The highest iron concentrations in consecutive leachates again generally are observed in the saprolite samples.

As for nickel, iron concentrations in the third leachate are higher than in the first leachate of several samples. Correlation analysis performed on the results from the sequential SPLP testing shows strong correlation between nickel and iron concentrations, some correlation between nickel and chromium and iron and chromium, and no correlation between pH and metals concentrations.

Comparison of Synthetic Precipitation Leaching Procedure Results to Effluent Standards

Although a direct comparison between SPLP leachate results and water quality criteria is of limited value, it can provide a general indication of parameters of potential environmental concern. The various SPLP tests conducted generally display a common theme with regard to exceedances of effluent standards. All exceedances are limited to pH, chromium, nickel and iron. The speciation of the total chromium measured in the entrained water was not determined, but for the sake of conservativeness it is assumed to be all in the hexavalent state. Individual exceedances for the four parameters are as follows:

exceedances for pH:

- bedrock samples only.

exceedances for chromium:

- all Ambatovy samples except the two Dynatec ferralite samples (FT-Am and FB-Am), the ferricrete/grenaille (G) and the bedrock sample; and
- both Analamay ferralite samples.

exceedances for nickel:

- three PDM saprolite samples (Pit 8 SAP, SAP-PDM, Hard SAP); and
- one PDM ferralite sample (NFER).

exceedances for iron:

- three PDM saprolite samples (Pit 8 SAP, SAP-PDM, Hard SAP);

- one sequential testing result for the PDM ferralite sample (NFER); and
- one sequential testing result for the PDM Bedrock sample.

The various exceedances indicate that most materials appear to have the capacity to release chromium, in particular the saprolite. Release of nickel and iron appears to be less prevalent, but may occur for certain types of saprolite and ferralite. Bedrock is unlikely to have an adverse environmental impact. Exceedances in bedrock leachates represent natural background and should not require mitigative actions.

3.2.2 Tailings

3.2.2.1 Chemical Composition

The results of the chemical analyses performed on two tailings solids samples from tailings neutralization (TN) tests 3 and 5 are presented in Table 2.1-10. The chemical compositions are consistent with the mineralogy, comprising principally hematite and gypsum [$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$] with lesser amounts of hydronium alunite [$(\text{H}_3\text{O})\text{Al}_3(\text{SO}_4)_2(\text{OH})_6$], silica and unleached chromite [FeCr_2O_4]. The compositions are typical of residues produced by pressure acid leaching of laterites.

Table 2.1-10 Chemical Composition of Tailings Solids

Analysis, wt%	Ni	Co	Al	Ca	Cr	Fe	Mg	Mn	Si	S
TN Test 3*	0.094	0.015	2.26	7.67	1.39	36.7	0.39	0.49	2.91	7.45
TN Test 5**	0.060	0.009	2.27	7.51	1.39	35.8	0.35	0.54	2.87	7.20

* May 11, 2004, 1300 to 1500 h, Table 11.34, Demonstration Campaign Report.

** May 14, 2004, 1300 to 1500 h, Table 11.35, Demonstration Campaign Report.

3.2.2.2 Acid-Base Accounting

The ABA and paste pH results for two tailings samples are summarized in Table 2.1-11. The sulphur contents of both samples are about 7 wt%, but the proportion of reactive sulphur (i.e., sulphide sulphur) is very low (<0.1 wt%). The remainder of the sulphur is present in the form of sulphate, consistent with the presence of gypsum and alunite. Values for paste pH are slightly alkaline.

Based on the B.C. Guidelines for prediction of ARD potential (Price, 1997), both samples are classified as being non-acid-generating with NPR values equal to or exceeding 4. Their lack of acid-generating potential is further supported by the very low sulphide sulphur contents (i.e., below 0.3 wt%) and the paste pH values > 5.5.

Table 2.1-11 Acid-Base Accounting (Tailings)

Parameter	Unit	SA #1	SA #2
paste pH	s.u.	7.45	7.60
total sulphur ^(a)	wt%	7.19	7.18
sulfide sulphur ^(a)	wt%	0.08	0.02
sulfate sulphur ^(a)	wt%	7.10	7.13
C total	wt%	0.09	0.08
C inorganic	wt%	<0.01	<0.01
acid neutralization potential (ANP) ^(a)	kg CaCO ₃ /ton	9.6	9.9
acid generation potential (AGP) ^(b)	kg CaCO ₃ /ton	2.5	0.62
net neutralization potential (NNP) ^(c)	kg CaCO ₃ /ton	7.1	9.4
neutralization potential ratio (NPR) ^(c)		3.8	16.0

^(a) The neutralization potential and sulphur forms are averages from triplicate analyses (PDM samples only).

^(b) AGP and NPR were derived using pyritic sulphur.

^(c) NNP and NPR were calculated using the detection limit of pyritic sulphur.

3.2.2.3 Tailings Solutions

Table 2.1-12 presents the analytical results from the various tailings solutions. Values in excess of effluent criteria are highlighted.

Despite having been generated by different methods, the chemical compositions of the solutions generally are similar. All solutions are circumneutral and have low trace metal concentrations. Elevated concentrations are observed for calcium, magnesium, manganese and sulphate. The high calcium and sulphate concentrations are consistent with the presence of significant amounts of gypsum.

Exceedances of World Bank effluent standards are observed for manganese, sulphate and conductivity in all samples. Since sulphate is the dominant dissolved constituent in the tailings solutions and occurs at significant concentrations, elevated values for conductivity are observed as well. One entrained water sample demonstrates a slight exceedance of the nickel effluent criterion as well.

3.2.2.4 Sequential Leaching

Table 2.1-13 presents the results from the sequential leach testing of two tailings samples. Values in excess of effluent criteria are highlighted.

Table 2.1-12 Tailings Solution Chemistry

Solution		Madagascar/World Bank Effluent Limits	Entrained Water			Supernatant		Drained Seepage from Settling Test
Continuous TN Test			3	3	5	3	3	
Pail			23	25	42	Proc 04-01	Proc 04-02	
pH	s.u.	6.0 - 9.0	6.62	6.1	7.65	7.28	7.26	6.85
Alkalinity	mg/L as CaCO ₃		26.0	11.1	87.0	39	35	26
Conductivity	µS/cm	200	8,420	8,130	9,380	7,570	7260	8210
Al	mg/L	5.0	< 0.003	0.0298	< 0.003	0.043	0.045	0.020
As	mg/L	0.1	< 0.001	< 0.001	< 0.001	< 0.005	< 0.005	< 0.005
Ba	mg/L		0.036	0.006	0.005	0.005	0.004	0.009
Ca	mg/L		420	429	423	420	433	517
Cd	mg/L	0.02	< 0.001	< 0.001	< 0.001	n/a	n/a	n/a
Cl	mg/L		12.2	12.3	11.6	12	13	15
Co	mg/L		0.043	0.0878	0.0594	0.0066	0.0057	0.0078
Cr	mg/L	0.5 / 0.05 ^(a)	0.0033	0.0049	0.0102	0.002	0.002	< 0.001
Cu	mg/L	0.3	0.0096	0.0337	0.0094	0.0016	0.0011	0.0045
F	mg/L		1.2	0.9	0.7	0.25	0.26	0.28
Fe	mg/L	2	< 0.003	< 0.003	< 0.003	0.04	0.03	< 0.02
Hg	µg/L	2	< 1	< 1	< 1	< 0.1	< 0.1	< 0.1
K	mg/L		0.400	0.406	0.428	0.91	0.68	1.86
Mg	mg/L		2,190	2,070	2,030	1,560	1,500	1,960
Mn	mg/L	5.0	260	219	222	218	200	240
Na	mg/L		0.0087	< 0.002	0.0516	7.95	1.74	1.45
NH ₃	mg/L as N	15	< 1	< 1	< 1	0.1	0.1	0.3
Ni	mg/L	0.5	0.097	0.519	0.0833	0.008	0.009	0.024
NO ₂	mg/L as N	0.2	< 0.02	< 0.02	< 0.02	< 0.06	< 0.06	< 0.6
NO ₃	mg/L as N	20	n/a	n/a	n/a	< 0.05	< 0.05	n/a
PO ₄	mg/L	10	< 0.1	< 0.1	< 0.1	< 10	< 10	< 10
Pb	mg/L	0.2	< 0.005	< 0.005	< 0.005	< 0.0002	< 0.0002	< 0.0002
Si	mg/L		0.784	0.751	0.496	0.85	0.83	< 0.602
SO ₄	mg/L	250	8,590	8,440	10,200	9,800	8,300	9,400
V	mg/L		< 0.002	< 0.002	< 0.002	0.0010	0.0014	< 0.0009
Zn	mg/L	0.5	< 0.002	< 0.002	< 0.002	0.0410	0.0240	0.250

^(a) Total chromium / hexavalent chromium.

Table 2.1-13 Sequential Leach Testing Results

Parameter	Unit	Madagascar/World Bank Effluent Limits	SA #1			SA #2		
			Leachate 1	Leachate 2	Leachate 3	Leachate 1	Leachate 2	Leachate 3
pH	s.u.	6.0 - 9.0	7.28	7.28	7.18	7.33	7.29	7.25
Alkalinity	mg/L as CaCO ₃		24	21	12	22	21	16
Conductivity	µS/cm	200	5430	3640	2910	5110	3580	2900
Al	mg/L	5.0	0.008	< 0.004	0.113	0.012	< 0.004	0.005
As	mg/L	0.1	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Ba	mg/L		0.090	0.053	0.006	0.090	0.053	0.053
Ca	mg/L		428	471	504	429	473	511
Cl	mg/L		5.7	7.1	9.8	5.2	4.7	3.1
Co	mg/L		0.0045	0.0027	0.0019	0.0038	0.0024	0.0017
Cr	mg/L	0.5 / 0.05 ^(a)	< 0.001	< 0.001	0.001	< 0.001	< 0.001	0.001
Cu	mg/L	0.3	< 0.0008	< 0.0008	< 0.0008	< 0.0008	< 0.0008	< 0.0008
F	mg/L		0.28	0.38	0.23	0.29	0.38	0.45
Fe	mg/L	2	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Hg	µg/L	2	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
K	mg/L		0.41	1.58	4.94	0.27	0.20	0.17
Mg	mg/L		934	440	233	951	427	226
Mn	mg/L	5.0	115	60	39	97	54	33
Na	mg/L		2.07	5.90	< 0.05	2.07	4.84	5.72
NH ₃	mg/L as N	15	0.1	< 0.1	n/a	0.1	< 0.1	n/a
Ni	mg/L	0.5	0.013	0.009	0.007	0.011	0.007	0.006
NO ₂	mg/L as N	0.2	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06
NO ₃	mg/L as N	20	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
PO ₄	mg/L	10	< 10	< 10	< 10	< 10	< 10	< 10
Pb	mg/L	0.2	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002
Si	mg/L		1.17	0.96	0.62	1.14	0.93	0.79
SO ₄	mg/L	250	5,500	3,200	2,600	4,800	3,100	2,700
V	mg/L		< 0.0009	< 0.0009	< 0.0009	< 0.0009	< 0.0009	< 0.0009
Zn	mg/L	0.5	0.027	0.010	0.001	0.025	0.009	0.005

^(a) Total chromium / hexavalent chromium.

Comparison Between Tailings Solutions and Results from Sequential Leach Testing

In general, reasonable agreement is observed between the chemical compositions of the various tailings solutions and the leachates from the sequential leach testing. In particular, the two supernatant solutions are similar to the sequential leachates, despite the fact that the various tailings samples have been generated by different methods.

Sequential Leach Testing

Values for pH vary only slightly (i.e., by less than about 0.1 pH unit) over the three sequential leaches conducted as part of the Dynatec characterization program. Trace metal concentrations generally are low. Chromium is not detected in any of the leachates at concentrations above its detection limit of 0.001 mg/L.

Nickel in consecutive leachates shows consistent decreases in concentration, as do manganese and sulphate. Nickel concentrations decline by a factor of about 2; manganese concentrations decline by a factor of about 3, and sulphate concentrations decline by a factor of about 2. Iron is not detected in any of the leachates.

Comparison of Sequential Leach Testing Results to Effluent Standards

Although a direct comparison between leachate results and water quality criteria is of limited value, it can provide a general indication of parameters of potential environmental concern. The sequential leach tests conducted display a common theme with regard to exceedances of effluent standards. All exceedances are limited to manganese, sulphate and conductivity, as was the case for the various tailings solutions. This is in contrast to exceedances observed for the mine rock and ore, which were generally limited to chromium, nickel and iron.

The various exceedances indicate that the tailings appear to have the capacity to release manganese and sulphate and generate solutions high in total dissolved solids (TDS). However, concentrations are reduced significantly as leaching progresses, which suggests that under long-term, operational conditions, the leachability of the tailings may be reduced to a level that no longer constitutes an exceedance of effluent standards. Long-term testing is currently in progress.

3.3 QUALITY ASSURANCE/QUALITY CONTROL

3.3.1 SGS Lakefield Research

SGS Lakefield Research is accredited by the Standards Council of Canada (SCC) and by Canadian Association for Environmental Analytical Laboratories (CAEAL), for specific environmental tests listed in the scope of accreditation. Currently the laboratory has over 95 analytical methods accredited to ISO/IEC 17025. ISO/IEC 17025 addresses both quality management and the technical aspects of operating a testing laboratory

The quality assurance system at SGS Lakefield Research consists of a documented quality system. All appropriate documentation (quality manual, methods, written instructions, standard operating procedures, and data approval criteria) is in place. As required, the Quality Control Co-ordinator is independent of the production area of the laboratory and reports directly to the Manager.

Quality control procedures are method specific and include duplicate samples, spiked blanks, spiked replicates, reagent/instrument blanks, preparation control samples, certified reference material analysis, and instrument control samples, as appropriate for the individual methods. Matrix matching of reference materials to samples is always attempted. Frequency of insertion of control samples is method specific and follows legislated guidelines

3.3.2 Dynatec Technology Services

Dynatec's Analytical Laboratory has been registered with ISO 9001 and ISO Guide 25 since the formation of the Analytical Laboratory in 1998. In 2003, the system was revised to meet the requirements of ISO 9001 - 2000 and ISO 17025. Currently, the Analytical Laboratory is registered to ISO 9001 - 2000.

Testing is performed in accordance with written analytical procedures. Stringent quality control is applied that include, where applicable, the following measures:

- run reagent blanks;
- check baselines;
- check calibration coefficients;
- analyze within the calibration range;
- run duplicates;

- perform spike recovery tests; and
- use quality control charts.

For project water samples analysis, ERA (Environmental Resource Associates) Certified Reference Materials were used wherever possible to ensure the validity of the calibration. Multi-Element QC samples were also used where ERA Certified Reference Materials were not available.

3.4 CONCLUSIONS

The geochemical testing program completed by Dynatec and PDM on ore body and tailings samples has resulted in several findings with potential environmental consequences. These findings can be summarized as follows:

It is Dynatec's opinion that the geochemical characterization program of ore was conducted on composite samples that are representative of the Ambatovy and Analamay ore bodies. Similarly, for the tailings, it is considered that the samples are representative of expected operational processing conditions.

Based on the ABA results, mine rock, ore and tailings are not expected to be acid-generating due to sulphide oxidation, although some mine rock and ore leachates may be slightly acidic by nature. Long-term testing of these materials to evaluate transient processes such as sulphide oxidation is therefore not required.

Leach testing demonstrates that the leachability of the samples generally is low. However, most mine rock and ore materials appear to have the capacity to release chromium, in particular the saprolite. Release of nickel and iron appears to be less prevalent, but may occur for certain types of saprolite and ferralite. Bedrock is unlikely to have an adverse environmental impact. Leachate concentrations may vary considerably, and expected relationships between pH and metal leachability are not always observed for the mine rock and ore. For the tailings, leach testing and analysis of tailings solutions indicates significant leachability of manganese and sulphate, resulting in high-TDS solutions.

Sequential leach testing demonstrates that the leachability of chromium, nickel and iron in mine rock and ore may persist over time. Long-term testing would be required to further evaluate the longevity of this leaching behavior. Similarly, manganese and sulphate concentrations in sequential leachates from tailings remain elevated, although concentrations do decline significantly with time.

Long-term testing is currently underway to further understand leaching behaviour.

Chromium, nickel, and iron concentrations in certain leachates from mine rock and ore exceed World Bank effluent standards, as do manganese and sulphate concentrations and conductivity values in tailings solutions and leachates from tailings. However, due to the limited ability of static leach tests to simulate ambient site conditions, this does not imply that such exceedances will indeed be observed on-site. For instance, the attenuation potential of aquifer materials and lithologic units will result in reduced concentrations relative to those observed during the leach testing. In addition, natural dilution occurring due to precipitation may result in significantly reduced concentration in mine effluents. Monitoring of on-site groundwater and surface water quality will assist in further identifying the potential for metal leaching under operating and closure conditions.

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VOLUME I

APPENDIX 2.1

ATTACHMENT 1

GEOCHEMISTRY GRAPHS

Figure 1 **Concentration Trends Major Oxides**

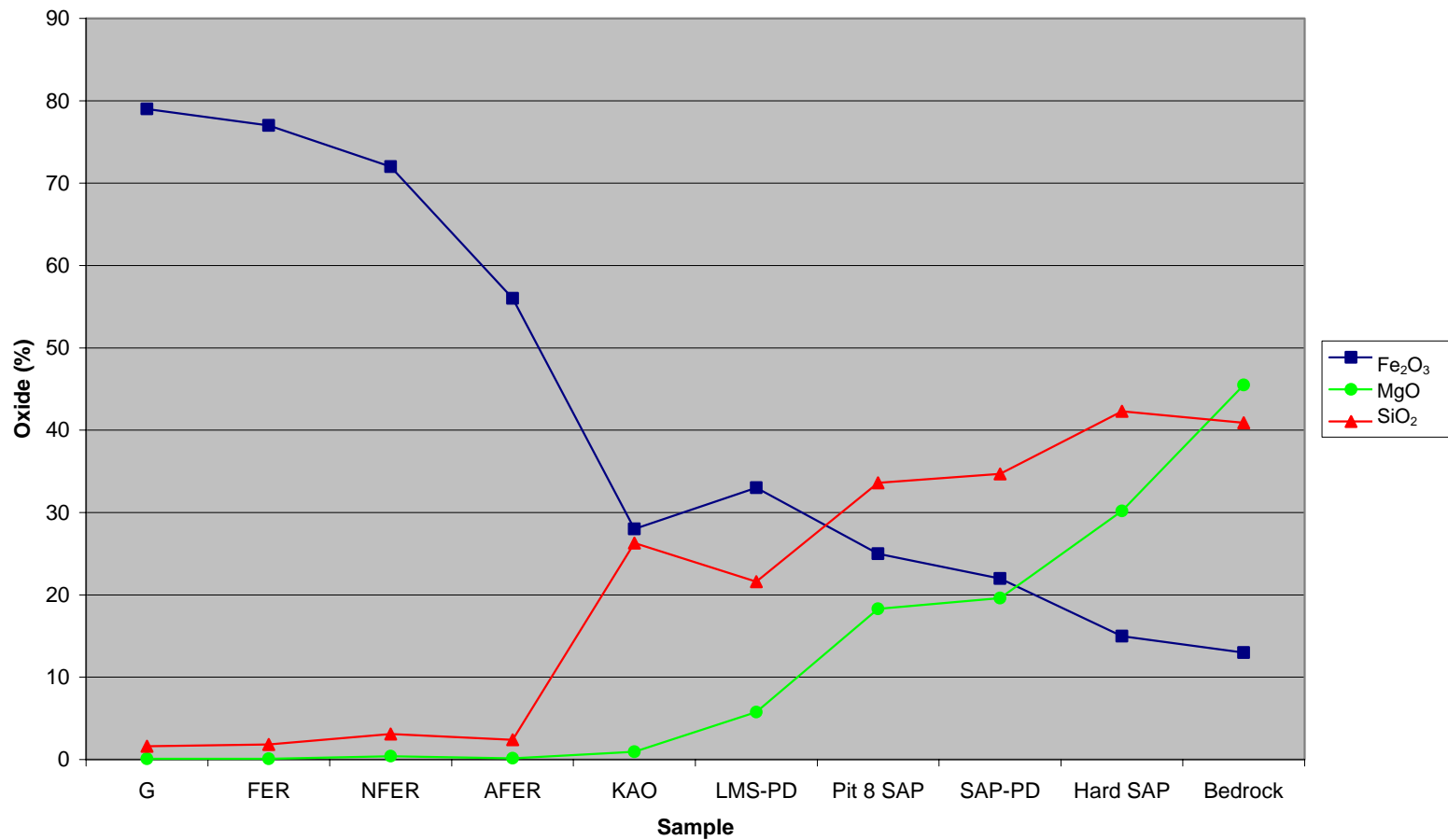


Figure 2 Chromium Leachability

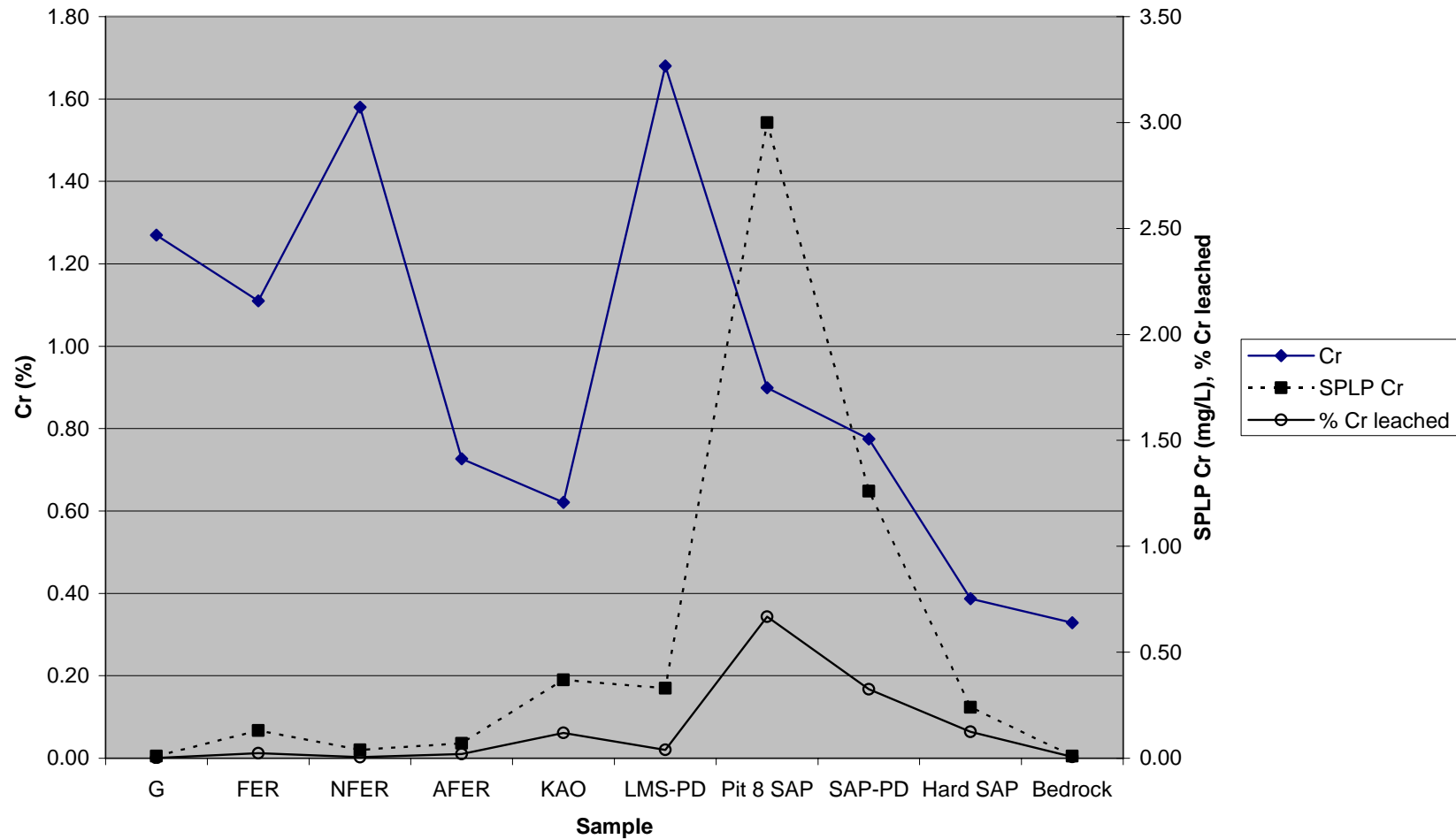


Figure 3 Nickel Leachability

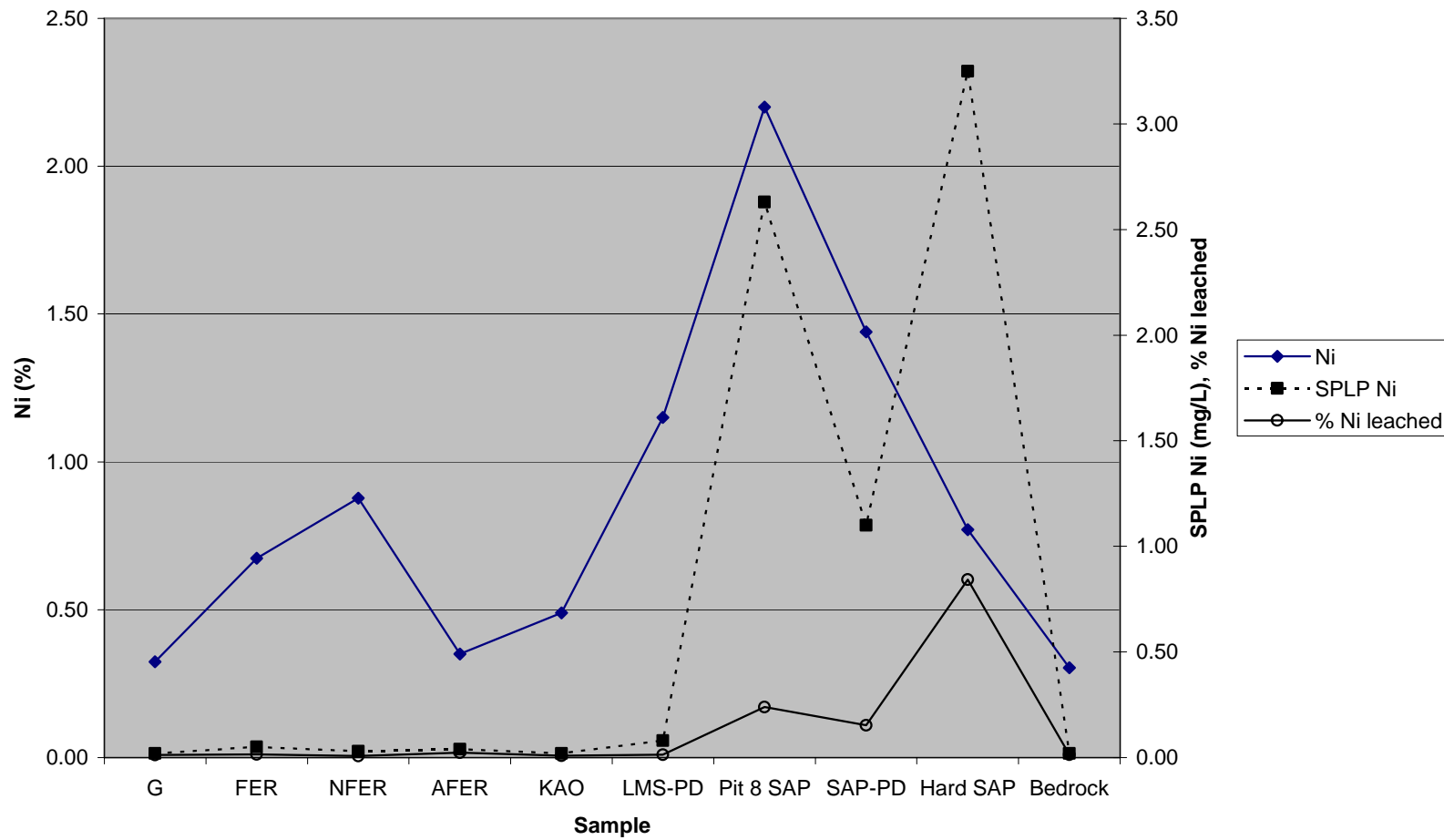


Figure 4 **Paste pH vs. Total Sulphur**

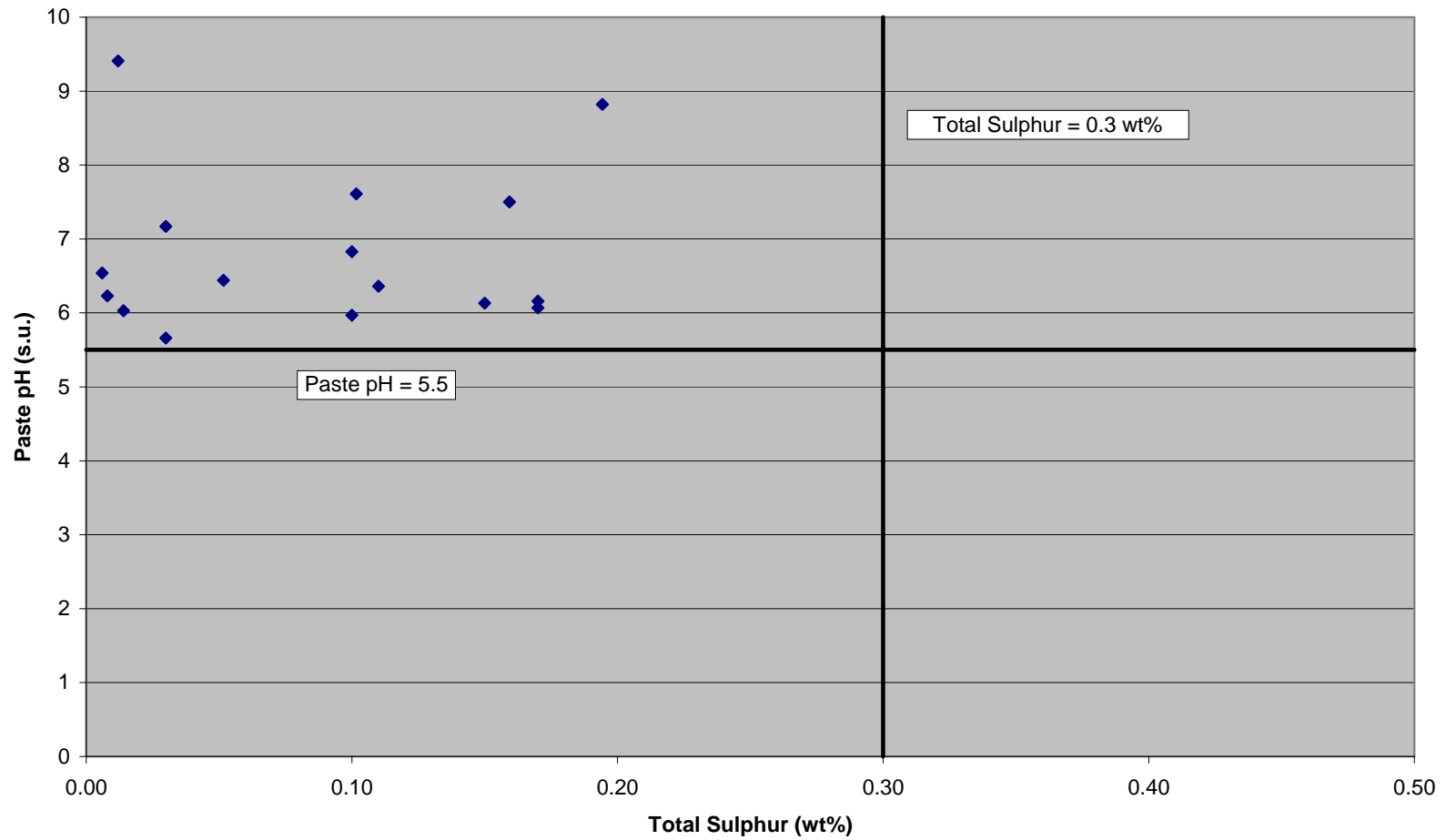


Figure 5 Iron Leachability

**Figure 7
Iron Leachability**

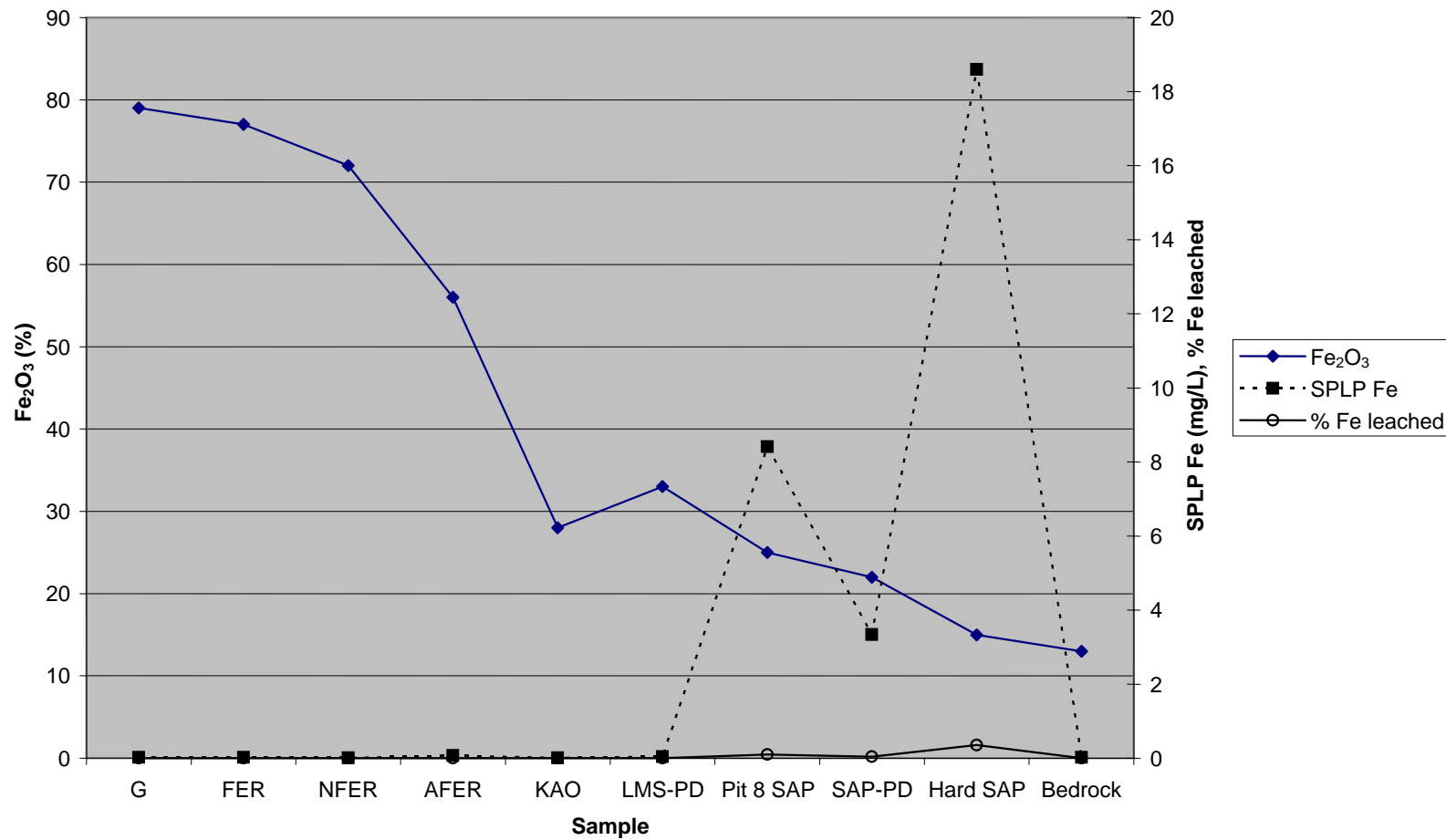


Figure 6 **Relative Leachability Dynatec vs. PDM Samples - pH**

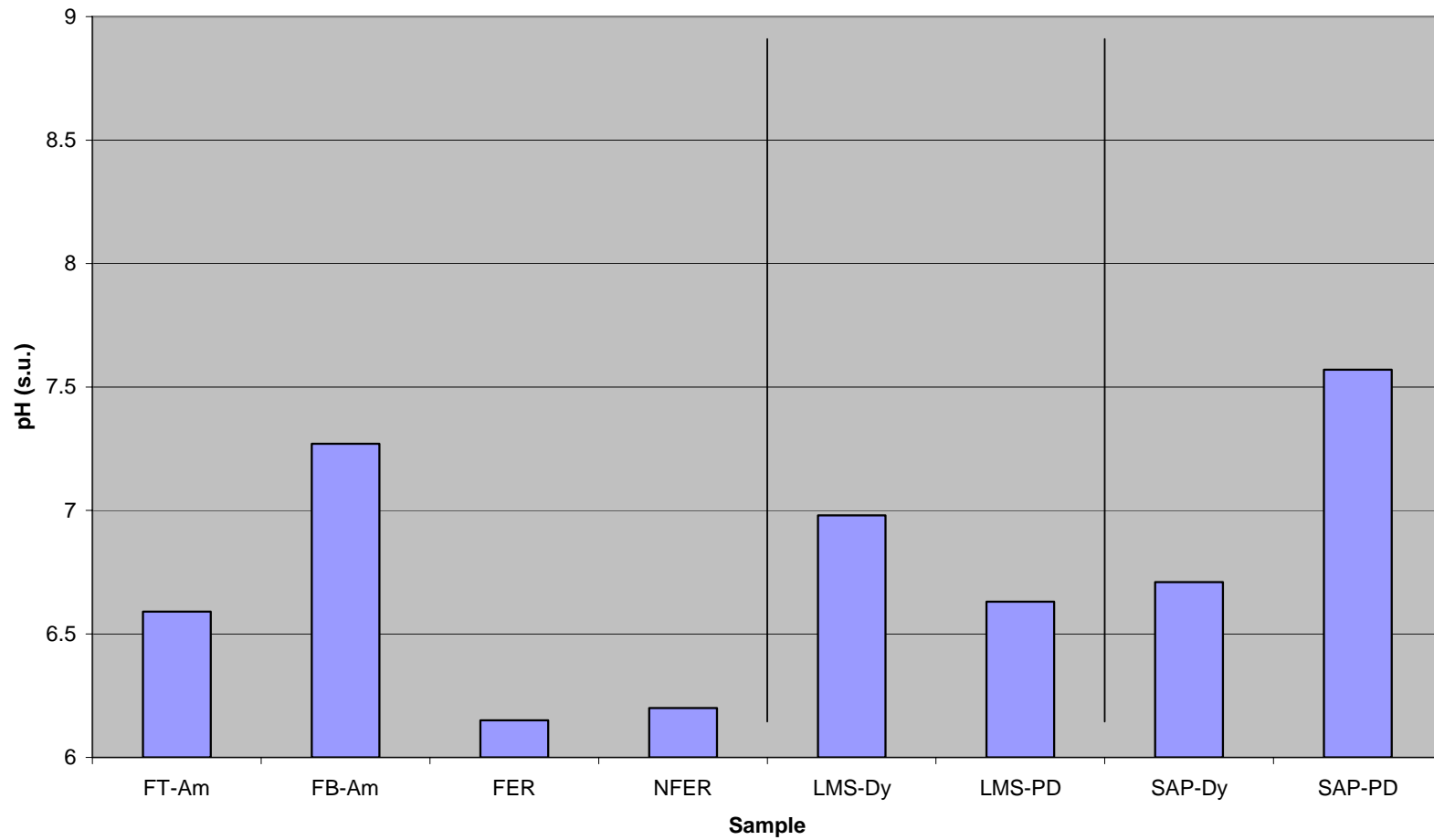


Figure 7 **Relative Leachability Dynatec vs. PDM Samples - Chromium**

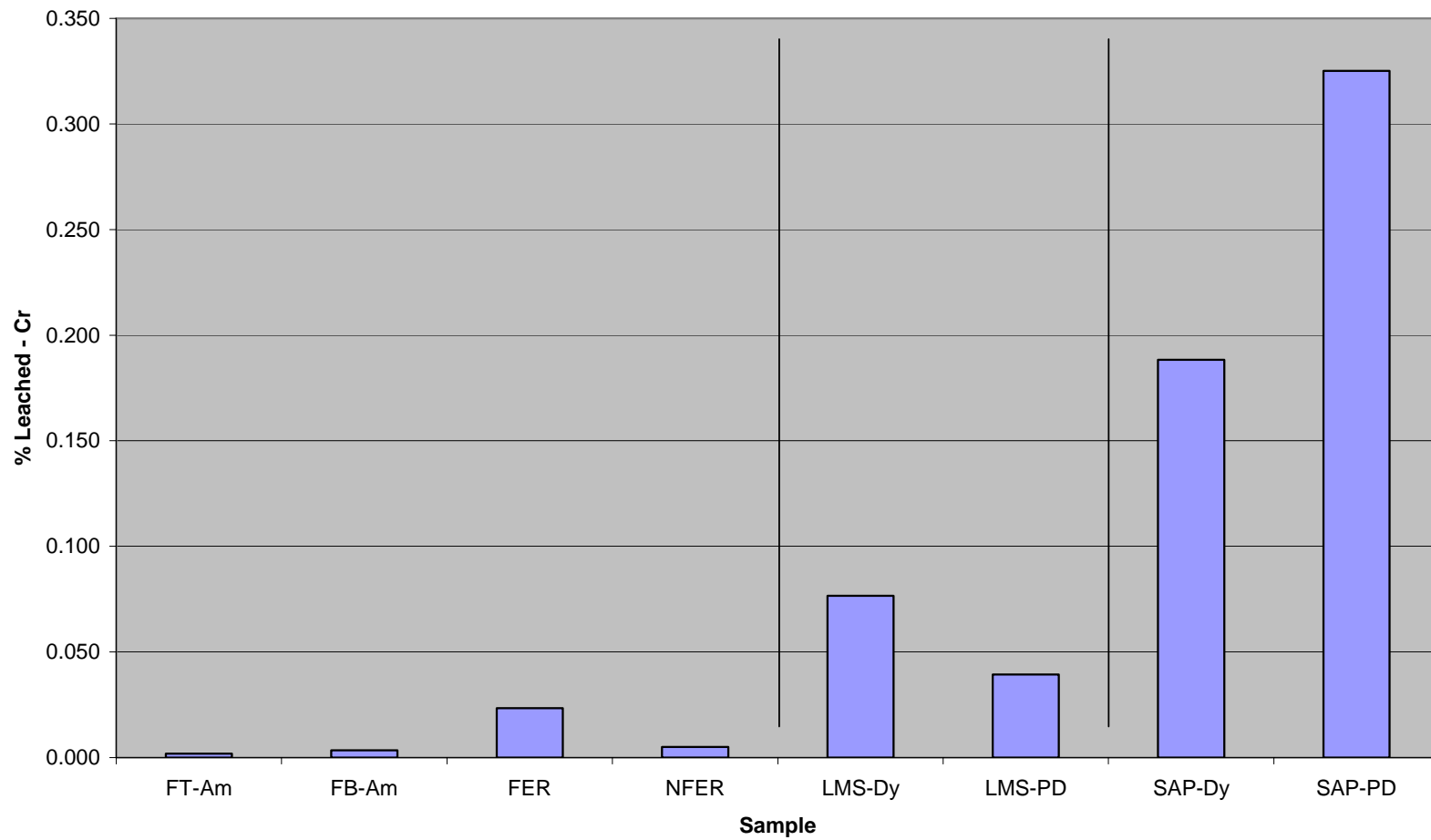


Figure 8 **Relative Leachability Dynatec vs. PDM Samples - Nickel**

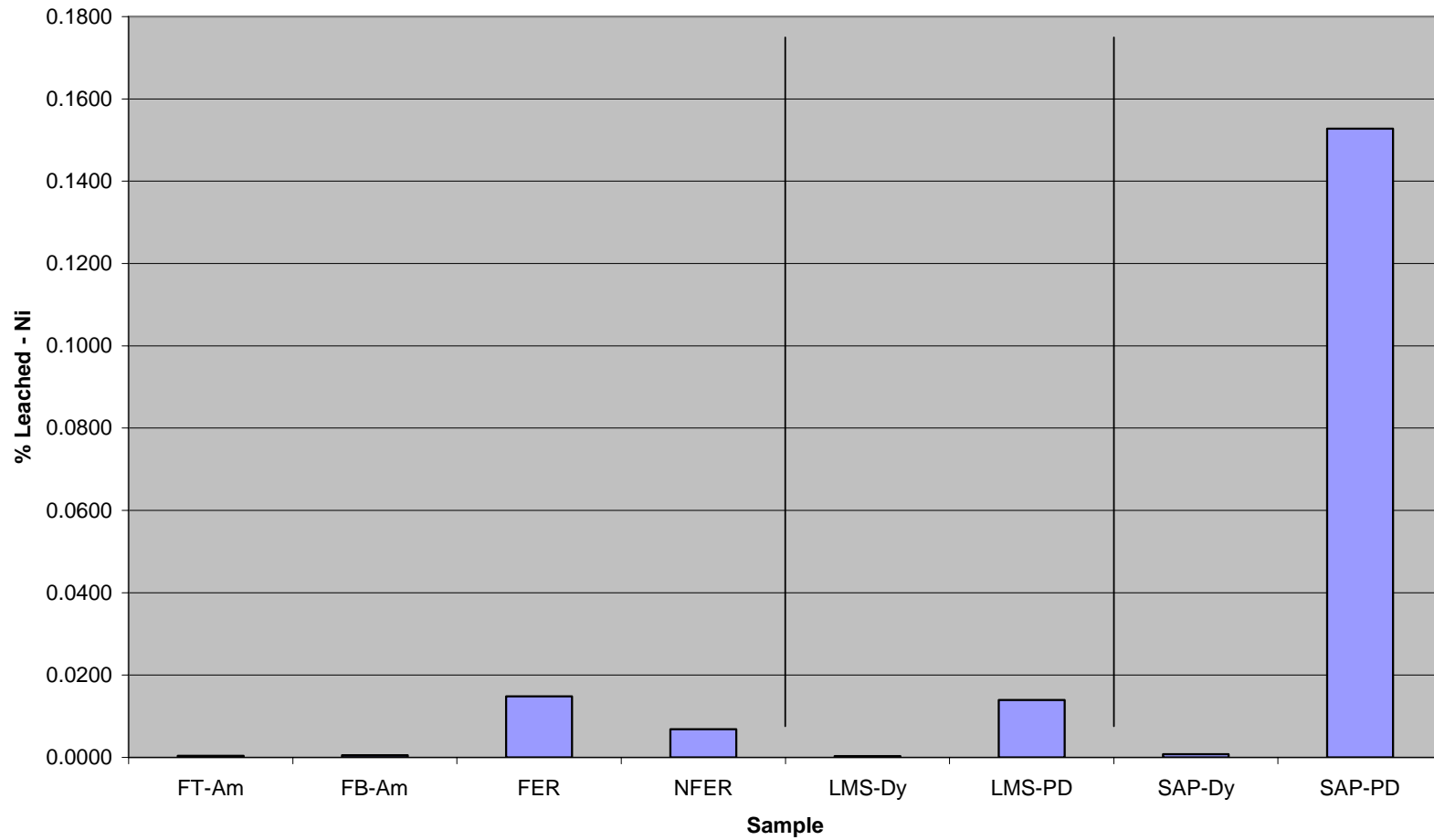


Figure 9 Relative Leachability Dynatec vs. PDM Samples - Iron

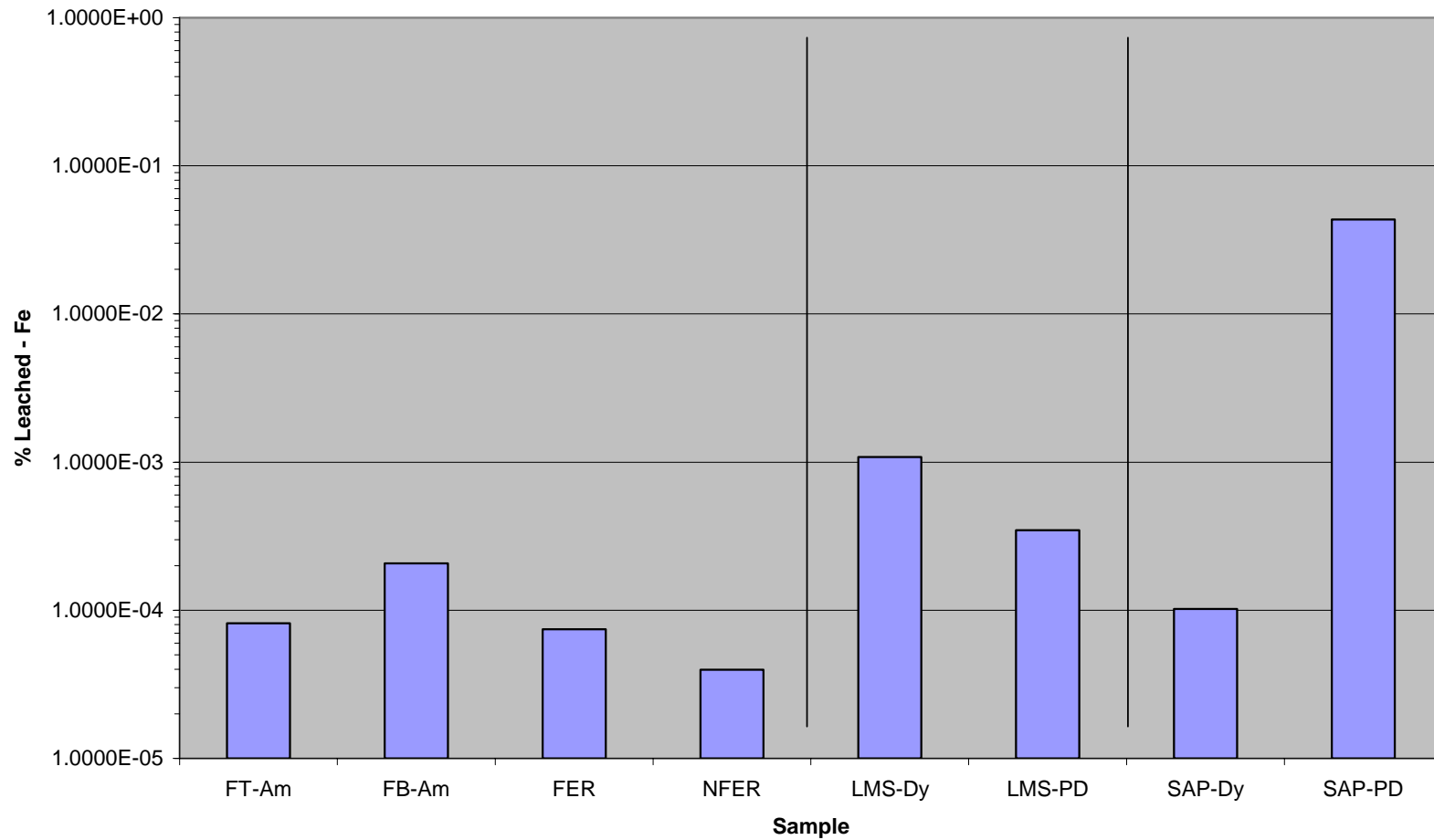


Figure 10 **Entrained Water vs. SPLP Results - pH**

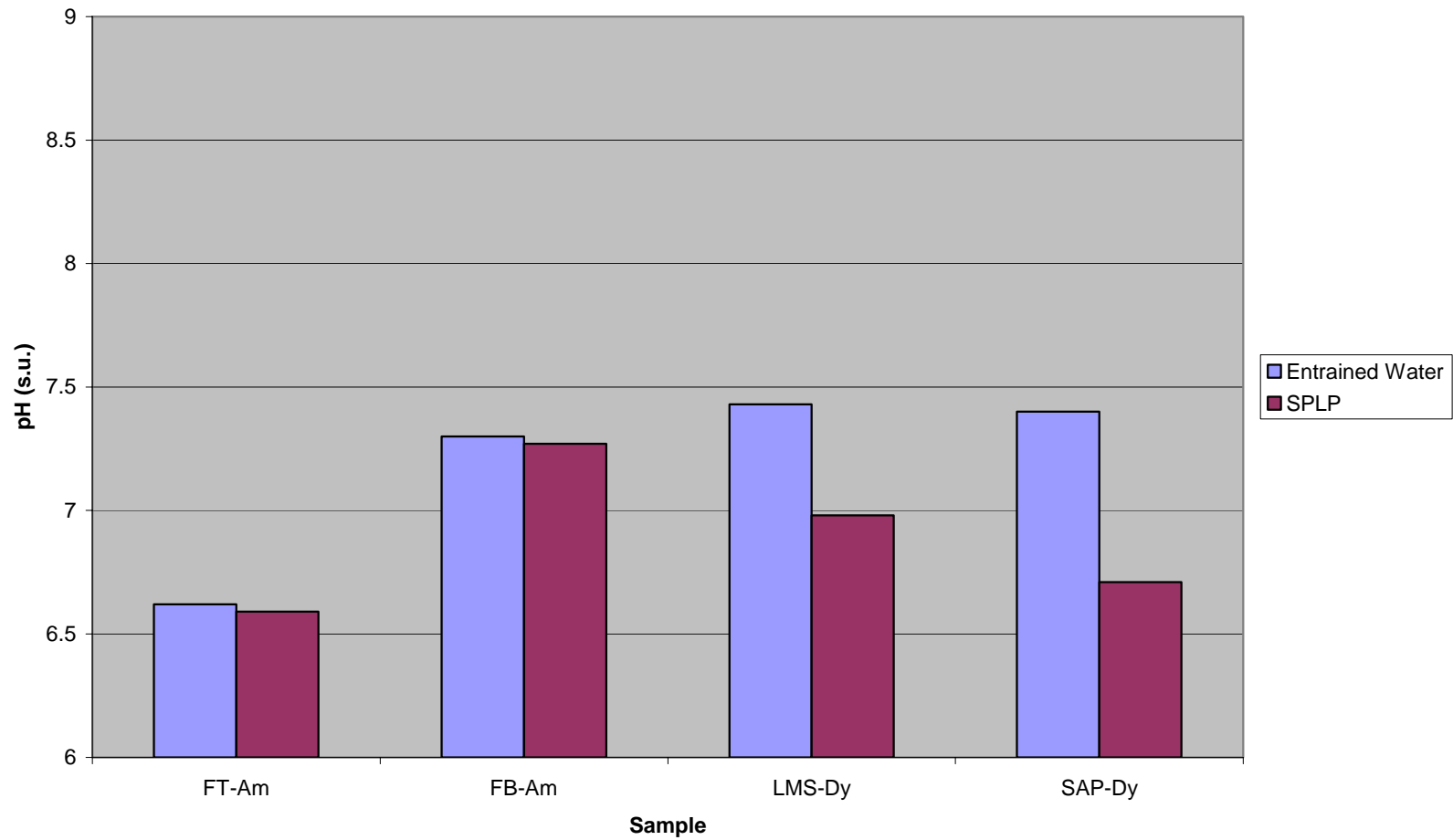


Figure 11 **Entrained Water vs. SPLP Results - Chromium**

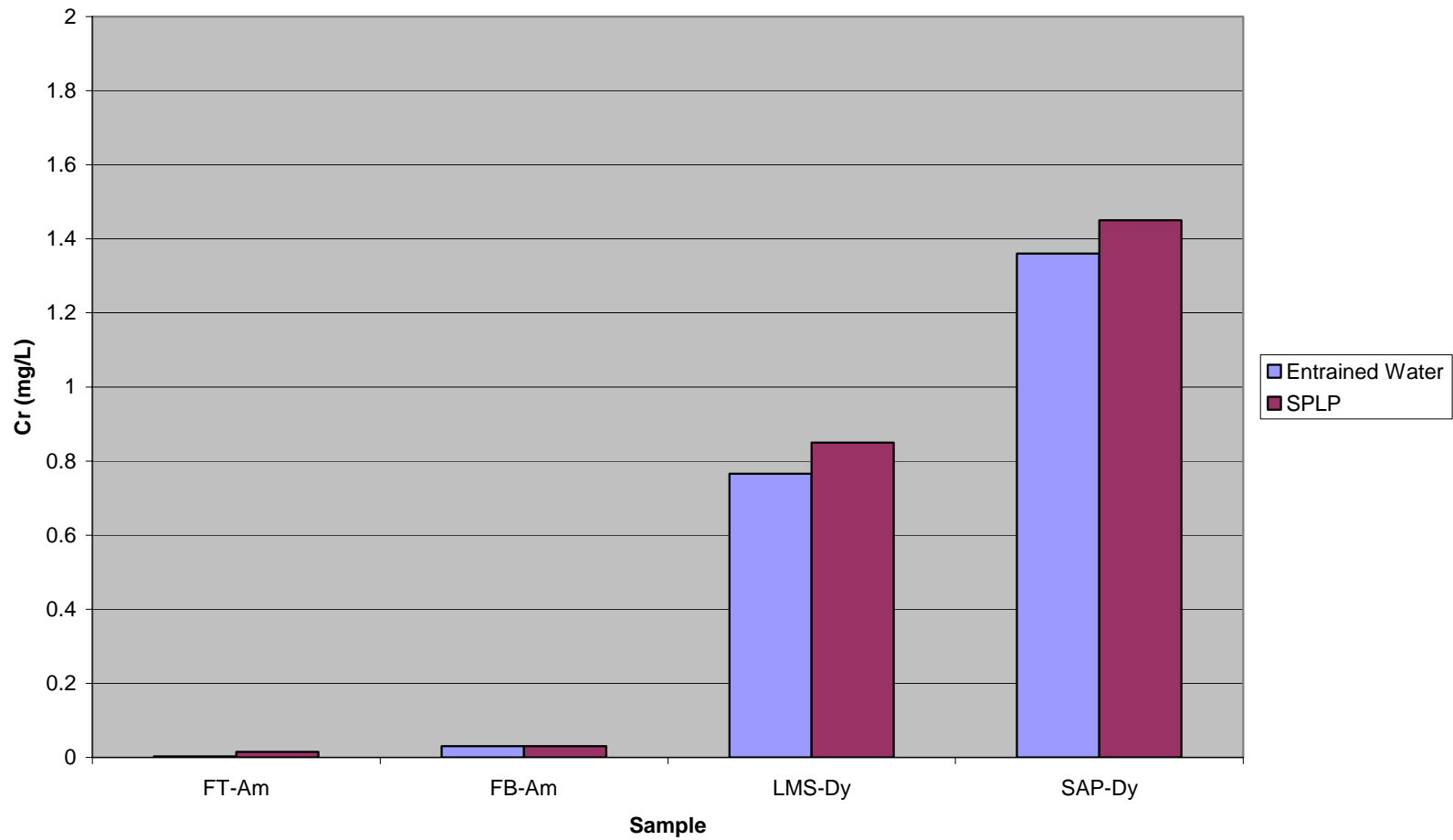


Figure 12 **Entrained Water vs. SPLP Results - Nickel**

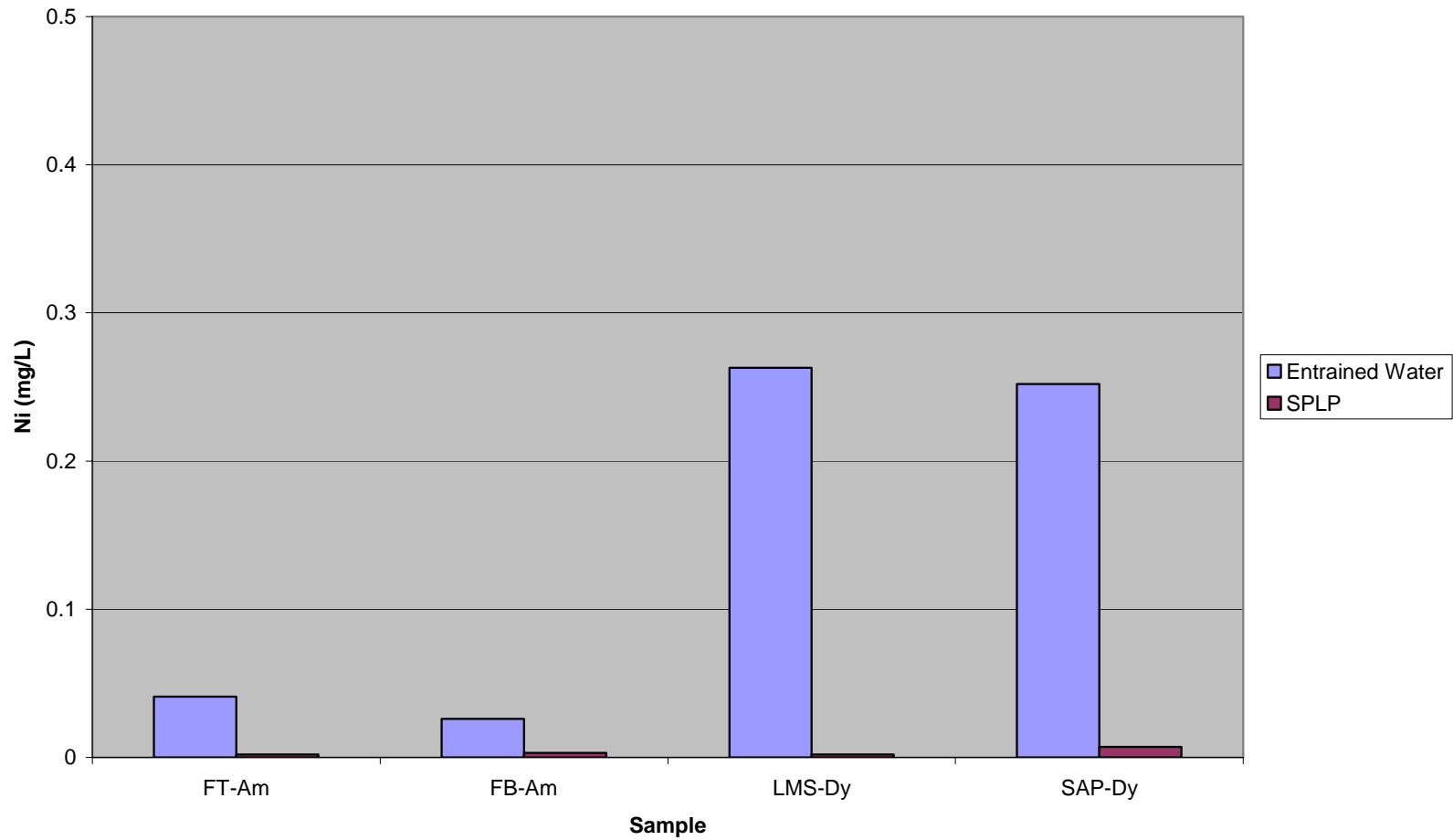


Figure 13 **Entrained Water vs. SPLP Results - Iron**

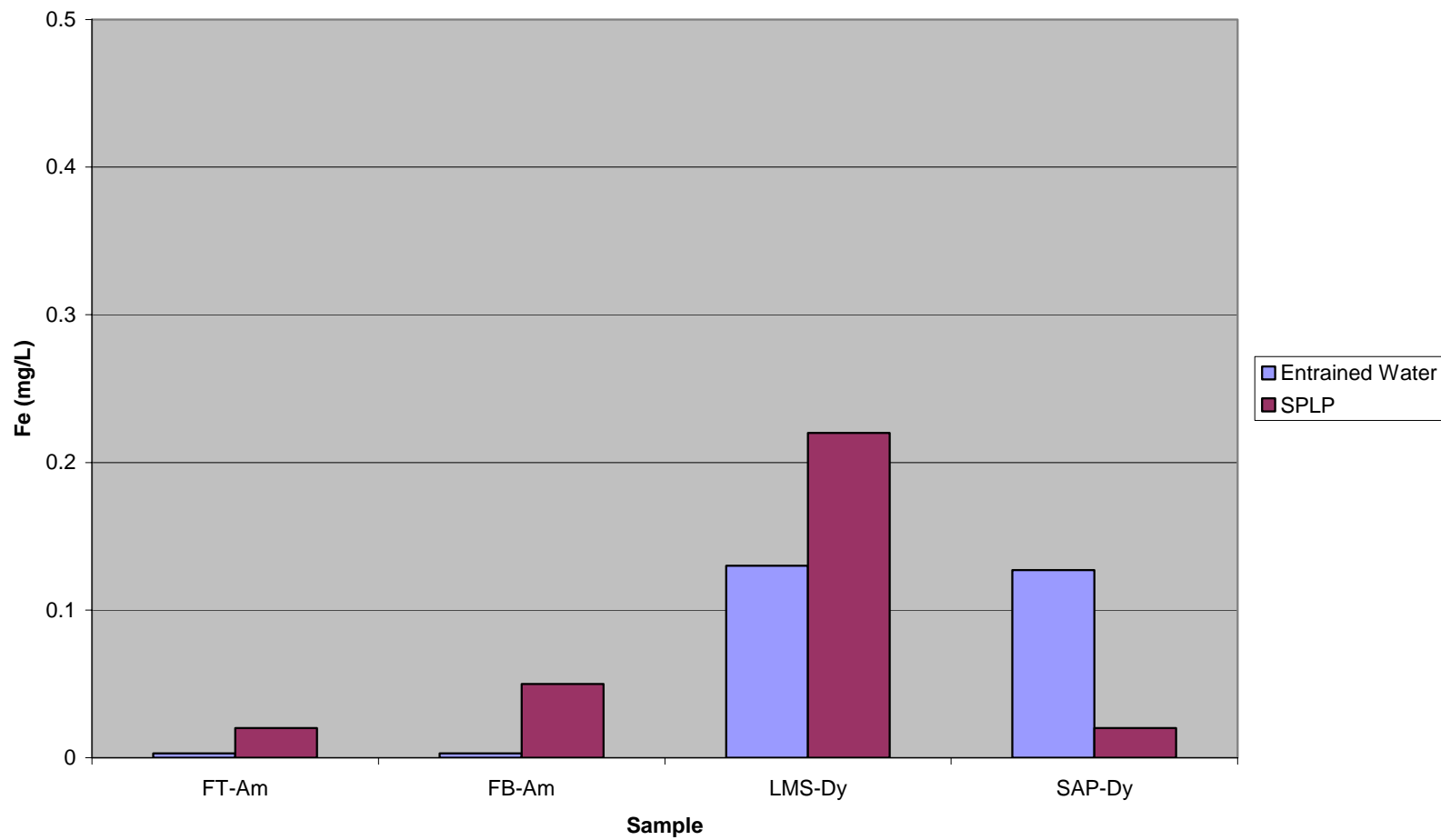


Figure 14 Consecutive SPLP - pH

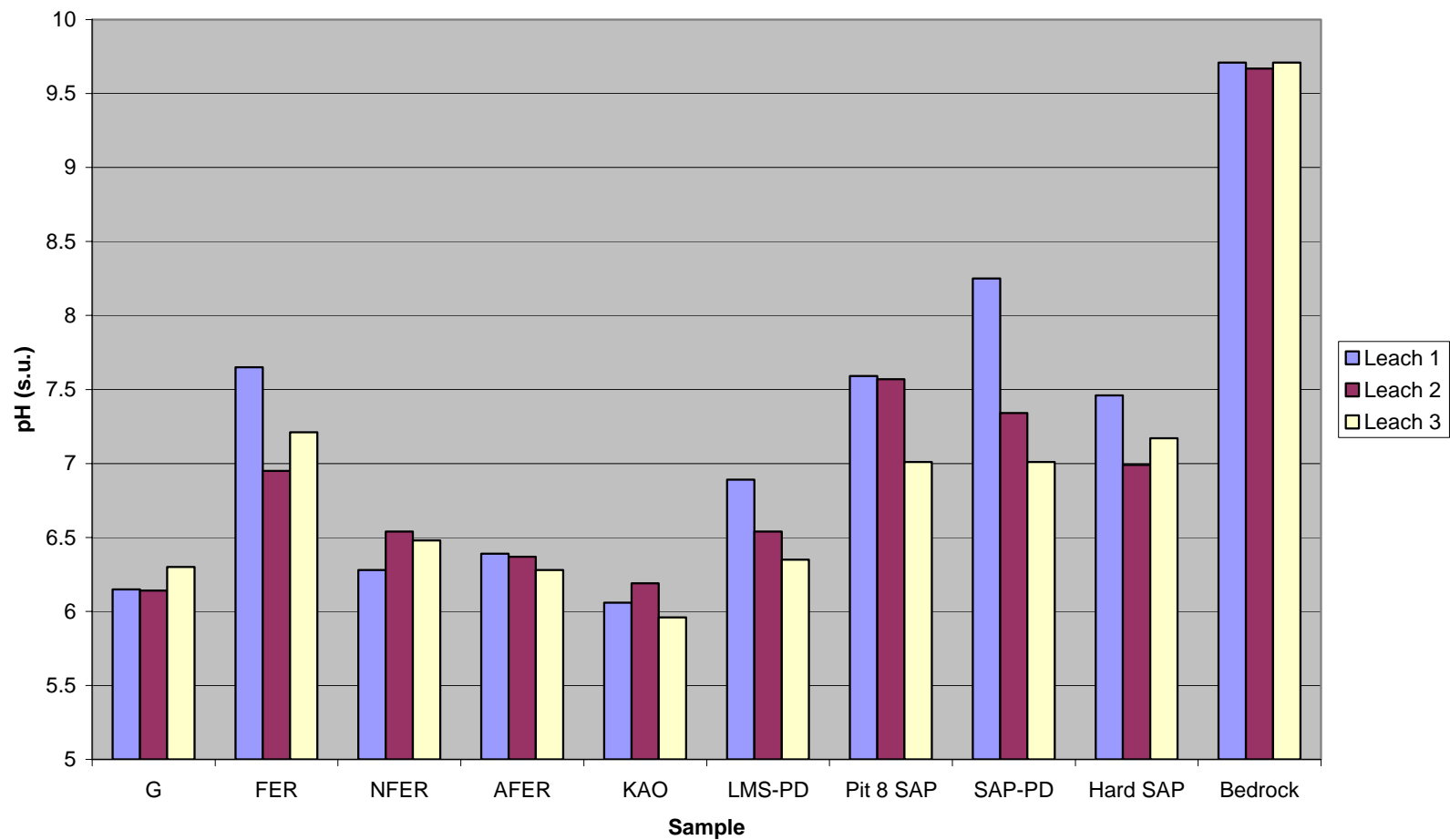


Figure 15 Consecutive SPLP - Chromium

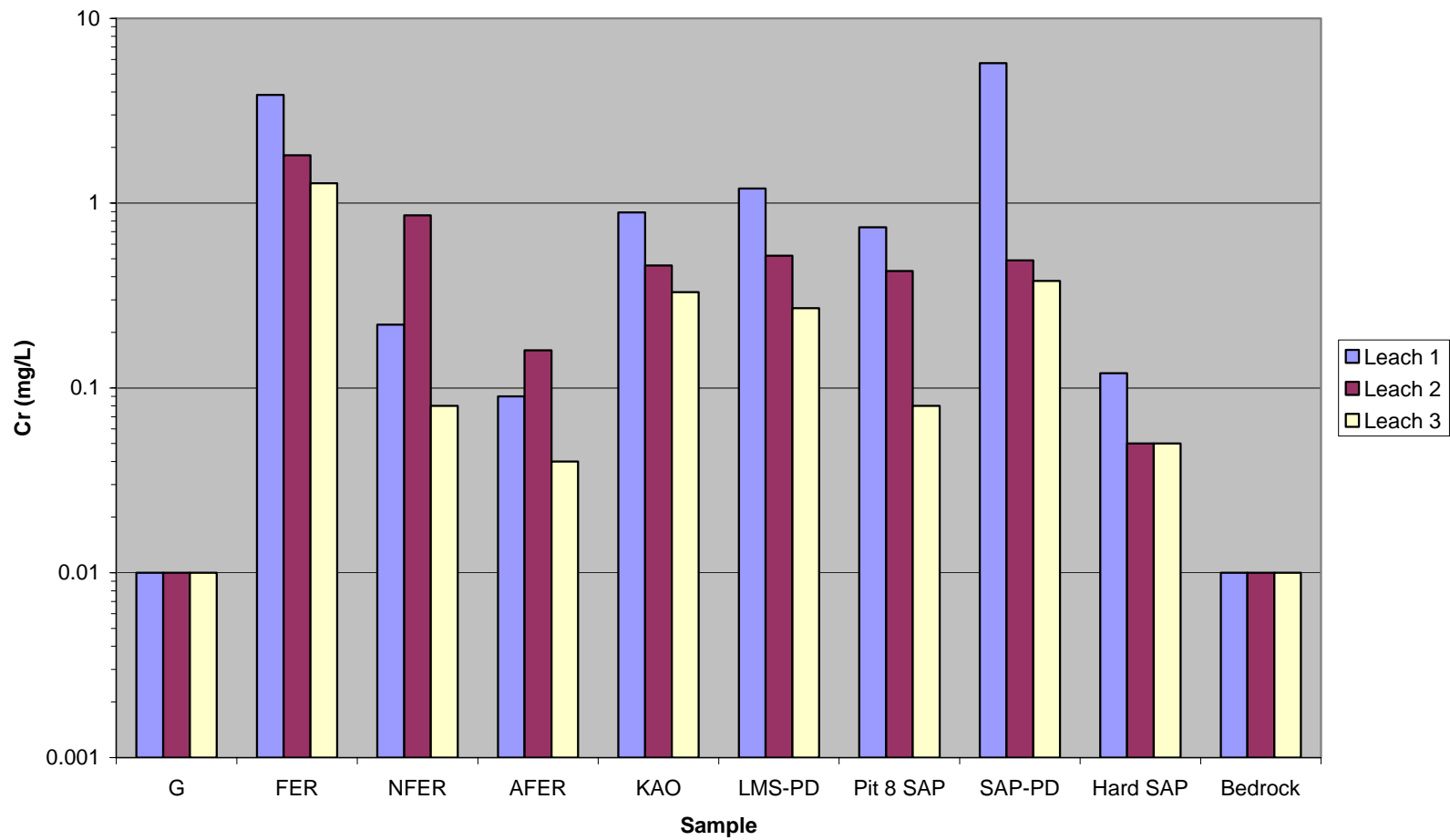


Figure 16 Consecutive SPLP - Nickel

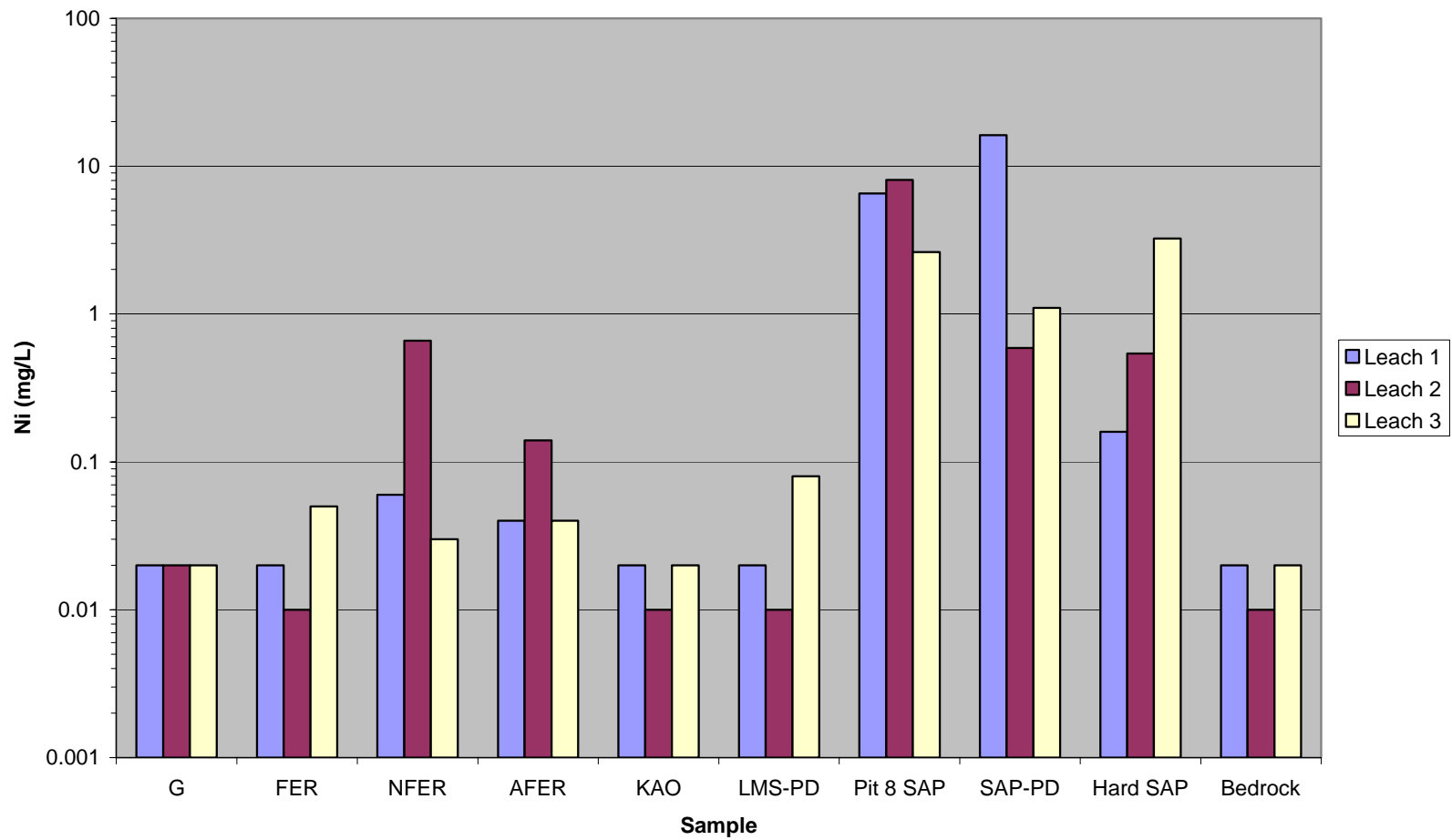
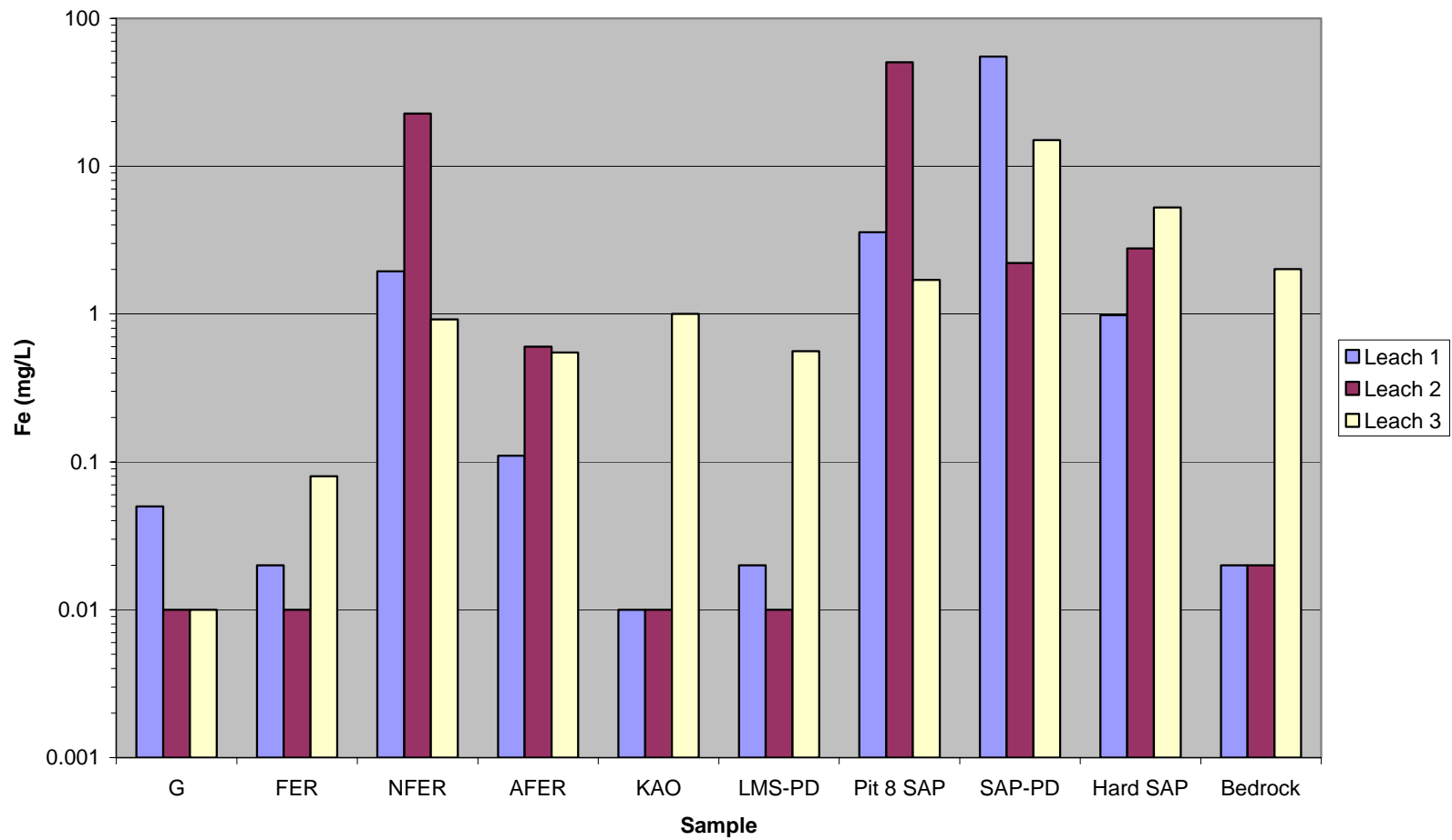


Figure 17 Consecutive SPLP - Iron



VOLUME I: PHYSICAL APPENDICES

APPENDIX 3.1

SOILS BASELINE

Submitted to:

Dynatec Corporation

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1 INTRODUCTION

This Appendix describes the baseline characteristics of soils within the mine, slurry pipeline, tailings facility and process plant local study areas (LSAs). The soils of the Ambatovy Project (the project) vary greatly depending on the soil forming factors, geology, topography, climate, biological activity and time. An interpretation of the reclamation suitability of soils is presented.

2 METHODS

The 2004 soil survey and mapping program consisted of a review of relevant literature about tropical soils common in the area and a field program on the mine site and slurry pipeline. Additional soils information on the tailings facility and plant sites comes from feasibility study geotechnical work.

The soil LSAs for this project were defined as the project disturbance footprints. For example, the mine LSA is the mine disturbance footprint, the tailings LSA is the tailings disturbance footprint and the slurry pipeline LSA is the pipeline disturbance footprint. Maps of the LSAs are outlined in Volume A, Section 7.2.

The mine soil survey was conducted by Jean Chrysostôme Randriamboavonjy (Volume I-3.1, Attachment 1). Soil pits were dug and described at each vegetation/soil inspection point. Soil pits were generally 50 cm in depth. For each soil horizon the following were recorded: colour, thickness, texture, structure, cohesion, porosity, rooting depth, and abundance of concretions. The soil profiles were classified using the French and American soil classification systems (CPC 1967, USDA. 1993, Volume I-3.1, Attachment 5). French and English soil profile descriptions are described in Volume I-3.1, Attachment 1. These transects were used in determining soil vegetation community relationships.

Representative A and B horizons were sampled and analyzed for pH (in a KCl solution), electrical conductivity, texture, organic matter (% OM), cation exchange capacity (CEC), exchangeable bases (Ca, Mg, K, Na) exchangeable aluminum, total phosphorus (A horizon only) and available phosphorus (A horizon only). Mine soil analytical properties are described in Volume I-3.1, Attachment 2.

The slurry pipeline soil survey was designed to develop a relationship between the soils and landscape position so that construction and reclamation recommendations could be tailored to certain topographic sequences. The soil survey was not designed to provide a comprehensive soil map of the proposed pipeline route. Aerial photographs were examined to assist in site selection and in soil interpretations. Each soil pit was excoriated to a depth of 1 m except in areas of shallow bedrock or over a shallow water table.

In general, soil profiles were described on three landscape positions (crest, slope and toe slope/depression) along three pipeline transects. Soil profile descriptions and chemical analysis were similar to the mine site survey. Soil profile descriptions for the pipeline are described in Volume I-3.1, Attachment 3 and soil chemistry in Volume I-3.1, Attachment 4.

3 RESULTS

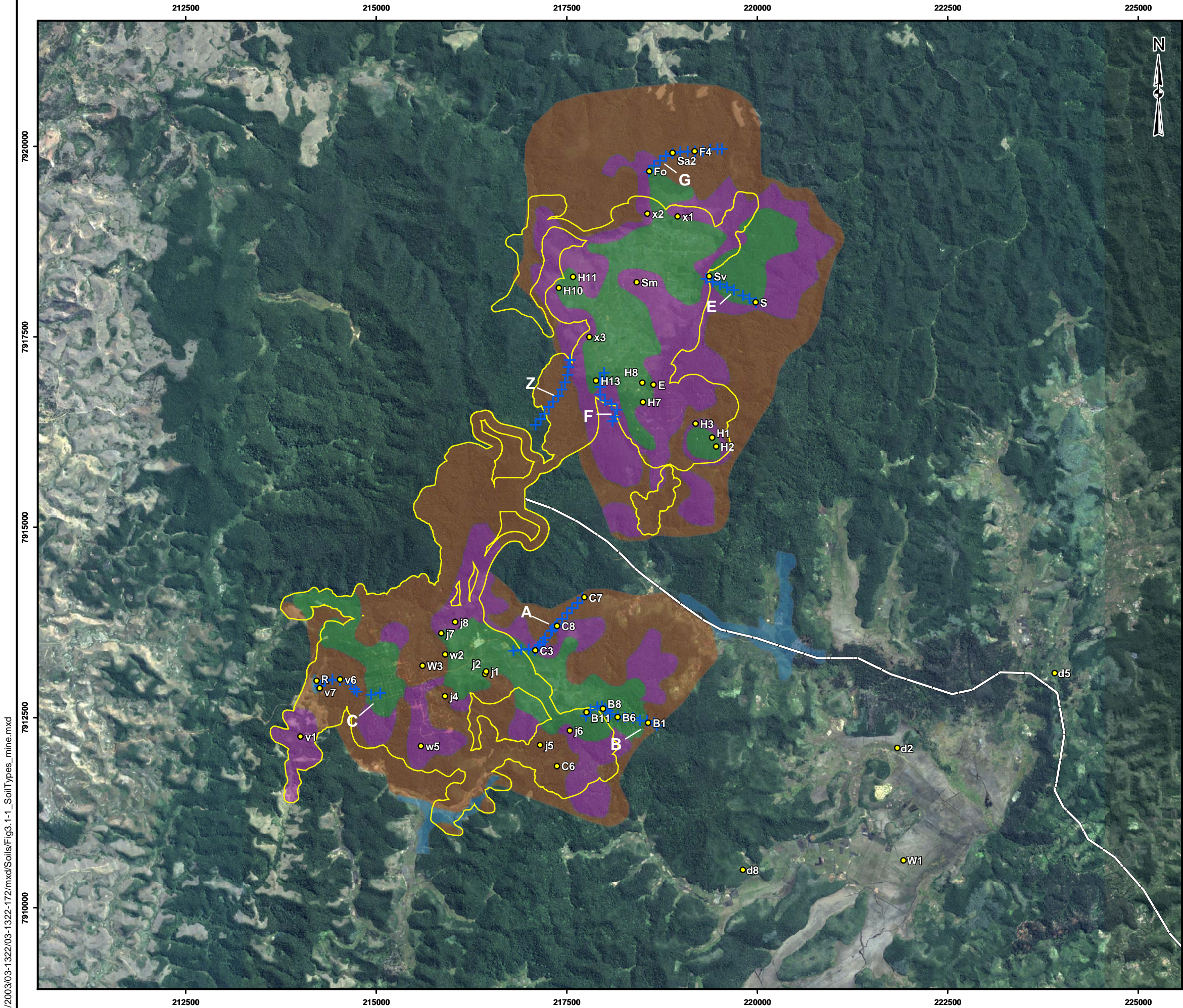
3.1 REGIONAL CONTEXT

Soils of the project region have developed on old, geomorphically stable terrain with almost no vestige of the original rock structure. Intense weathering in the humid tropics from high temperatures, abundant moisture and time has resulted in deep soil development. Tropical soils are generally low in nutrients due to the high rainfall which promotes weathering and leaching of minerals through the soil profile and out of the root zone. Favourable soil temperatures and moisture conditions favour high levels of biological activity including organic matter production and its rapid degradation. Nutrient holding capacity of soils in the humid tropics is mainly a function of humus content and is very low where humus content is low (Whitmore 1975). These facts explain why roots are concentrated at the soil surface even though many tropical subsoils do not have any physical characteristic that would restrict rooting. Reclamation of these soils is often difficult because they are poor in nutrients, notably nitrogen and phosphorus (Zonn 1986).

The soils in the region are generically known as laterites, which are defined as highly weathered iron-rich tropical soils (Young 1976). The word *laterite* has been widely used in the literature to describe soils of the tropical and subtropical regions of the world. These general terms are often used to describe various morphologic, physical, and chemical properties.

Laterite formation involves the redistribution and concentration of sesquioxides within the soil profile and are classified as Ultisols and Oxisols in the United States Department of Agriculture (USDA) soil classification system (Whitmore 1975). As described in USDA (1975), Aubert (1954) and Maignien (1966), the term laterite is indicative of the following soil properties:

- materials rich in iron and /or aluminum oxides;
- a combination of physical and chemical phenomena resulting in extreme alteration of soil-forming rock; separation of Fe, Al, Mn and Ti in soil horizons and migration of silica to the base of the soil pedon and forming hardpans;
- extremely low content of exchangeable alkaline and alkaline-earth bases;
- low cation exchange capacity (16 meq/100 g of soil or less);
- $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratios < 2 ;



LEGEND

- SOIL INSPECTION POINT
- SOIL/VEGETATION TRANSECT
- PROPOSED SLURRY PIPELINE ROUTE
- MINE FOOTPRINT


SOIL TYPE

- PISOLITE
- ARMoured FERRICRETE
- RED YELLOW FERRILITIC
- ORGANIC

REFERENCE

IKONOS Imagery provided by Space Imaging Inc.; Captured August 11, 2004
Datum: WGS 84 Projection: UTM Zone 39S



PROJECT		AMBATOVY PROJECT	
TITLE		MINE AREA SOIL INSPECTION POINTS AND SOIL CLASSIFICATION	
	PROJECT No. 03-1322-172.6300		SCALE AS SHOWN REV. 0
	DESIGN	MZ 12 May 2005	FIGURE: 3.1-1
	GIS	CK 23 Jun. 2005	
	CHECK	GJ 10 Feb. 2006	
	REVIEW	DM 10 Feb. 2006	

The soil legend for the mine area is summarized in Table 3.1-1.

Table 3.1-1 Soil Legend for the Mine Area

Soil Type	CPCS (French system)	Soil Taxonomy (USDA 1993)	Location
Armoured Ferricrete	humus-bearing immatured soil	Entisol	plateau
	indurated ferrilitic soil(outcrop of ferricrete)	Oxisol	plateau
	ferrilitic soil highly desaturated	Oxisol	plateau
Pisolites (soils containing gravel-like concretions)	ferrilitic soil highly desaturated	Oxisol	level and nearly level topography
	ferrilitic soil highly desaturated and bleached	Ultisol	side slopes
	immature soil from erosion or fill	Entisol	steep slopes and plateau
Red/Yellow Ferrilitic	red and yellow on top of red ferrilitic soil highly desaturated	Oxisol	level and nearly level topography
	red and yellow on top of red ferrilitic soil highly desaturated	Ultisols	moderate slopes
Organic	peat organic hydromorphic soil	Histosol	depressions



Photograph 3.1-1 Armoured Ferricrete Site



Photograph 3.1-2 Ferricrete Soil Profile (Note – Cuirasse Layer and Impediment to growth of roots)



Photograph 3.1-3 Pisolite Soil Profile



Photograph 3.1-4 Transitional Forest often Associated with Pisolite Soils



Photograph 3.1-5 Red Yellow Ferrillitic Soil

3.2.2 Soil Chemistry

Soils in the mine area are predominantly lateritic, with low nutrients and low organic matter. Analytical results (Table 3.1-2) indicate that the soils are strongly acidic (most soils pH < 5.0), are very low in base saturation (base saturation < 20%) and have low available nutrients (available phosphorous and total nitrogen). In addition, the low cation exchange capacity of many of the soils (< 10 meq/100 g) suggest that they will have a low nutrient retention capacity. The exception is phosphorous, which is likely to be fixed, and not very available for plants (Juo and Franzluebbbers 2003).

Table 3.1-2 Mine Soil Chemical Results – Upper Soil Horizon

Sample	Soil Type	pH (in KCl solution)	Electrical Conductivity (mmho/cm)	C%	N%	Available P (ppm)	CEC meq/100g	Base Saturation %	Al ³⁺ meq/100g	H ⁺ meq/100g
B 111	armoured ferricrete	4.35	160	6.38	0.343	37.9	14.4	6.6	1.82	2.6
B 61	armoured ferricrete	3.74	95	5.19	0.273	22.2	4.2	11.3	0.52	0.728
B 81	armoured ferricrete	3.6	202	4.1	0.189	31.1	9.8	8.7	0.208	1.14
C 61	armoured ferricrete	4.33	100	3.31	0.217	40	8.6	4.6	0.26	0.442
J 71	armoured ferricrete	4.0	100	5.56	0.273	17.3	22.6	1.2	2.13	2.83
Sa 21	armoured ferricrete	5.21	143	5.02	0.231	5.4	9.7	9.3	0.52	0.88
Sv 1	armoured ferricrete	3.83	65	2.91	0.091	4.3	8	8.7	0.104	0.868
C 31	pisolite	3.76	42	3.65	0.168	10	6.4	2.0	0.52	0.676
J 41	pisolite	4.07	190	4	0.252	2.2	13.8	6.7	0.52	0.77
J 61	pisolite	3.64	86	3.31	0.189	11.9	9.5	2.5	1.61	2.18
J 81	pisolite	4.44	142	4.09	0.252	1.1	6.3	8.7	0.312	0.66
S 1	pisolite	4.05	131	4.01	0.294	26.7	10.9	3.3	0.832	1.06
Sm 1	pisolite	4.47	27	3.08	0.161	1.1	6.7	4.1	0.416	0.448
V 11	pisolite	4.3	95	2.62	0.14	20.6	9.4	14.3	0.26	0.87
V 21	pisolite	3.61	65	3.07	0.196	6.7	5.8	2.9	0.36	0.57
W 51	pisolite	4.12	135	3.12	0.161	11.9	6.9	10	0.7	1.16
X 11	pisolite	4.01	28	6.76	0.154	18.9	4	7.9	0.16	0
X 21	pisolite	4.19	65	4.9	0.231	10	8.5	4.8	0.42	1.5
X 31	pisolite	4.12	31	4.65	0.287	10	4.1	5.1	0.364	0.34

Table 3.1-2: Mine Soil Chemical Results –Upper Soil Horizon (continued)

Sample	Soil Type	pH (in KCl solution)	Electrical Conductivity (mmho/cm)	C%	N%	Available P (ppm)	CEC meq/100g	Base Saturation %	Al ³⁺ meq/100g	H ⁺ meq/100g
B 11	red yellow ferrilitic	4.33	220	4.82	0.329	15.2	18.2	9.4	1.04	1.76
C 71	red yellow ferrilitic	4.5	139	3.14	0.231	3.3	6.7	8.3	0.16	0.156
C 81	red yellow ferrilitic	4.21	137	4.43	0.105	13	9.6	7.1	1.19	1.72
J 11	red yellow ferrilitic	4.51	76	1.93	0.217	1.1	8.9	5.0	0.156	0.384
J 21	red yellow ferrilitic	4.81	123	3.78	0.175	6.7	8.1	10.0	0.104	0.22
J 51	red yellow ferrilitic	4.3	100	3.06	0.21	24.9	7.6	6.9	0.88	1.22
R 1	red yellow ferrilitic	4.6	144	8.51	0.7	1.1	48.1	6.3	0.52	1.47
V 61	red yellow ferrilitic	5.1	225	2.78	0.182	40.1	12.3	10.4	0.052	0.11
V 71	red yellow ferrilitic	4.17	102	1.78	0.049	28.9	7.1	19.3	0.676	0.88
W 21	red yellow ferrilitic	4.31	225	4.11	0.357	3.3	7.3	14.3	0.57	0.88
W 31	red yellow ferrilitic	3.89	60	1.42	0.133	2.2	9.9	4.1	0.62	0.83

3.2.3 Topsoil Suitability for Reclamation Salvage

The suitability of a topsoil as a resource for reclamation is dependent on the intended use of the topsoil. Topsoils intended for reclamation should have a sufficient depth and quality to permit economic salvage and be of suitable quality and texture. Another consideration for salvage is the limited accessibility of equipment on steep slopes and rocky terrain. Topsoil volume estimates related to mine disturbance are not available at this time.

Based on the soil survey results, it is expected that the soils in the mine area will be extremely low in essential plant nutrients. The capacity of these soils to retain amendments and fertilizers will likely be low as well.

Soil salvage is typically considered to be infeasible on slopes greater than 40% and/or when coarse rock fragments are greater than 40% (by volume). Only those soils which are relatively extensive are considered practical for salvage using conventional heavy equipment. Since the ferricrete soils have a hardpan at the surface, topsoil salvage is not practical on these soils.

3.2.4 Land Suitability Assessment Mine Study Area

Agricultural land suitability ratings were assigned based on the agricultural systems found in or adjacent to the mine site area using the FAO system (FAO 1976, Attachment 6). These three agricultural systems are shifting cultivation (tavy) practiced at the edge of forested area, rain-feed (tanety) agriculture practiced on lower slopes bordering wetland rice field and wetland rice cultivation is practiced in some wetland areas outside the mine study area. Other types of agricultural, agroforestry or aquaculture systems are practiced along slurry pipeline corridor, tailings pond or port facility but these are not addressed in the land suitability classification.

3.2.4.1 Agriculture Systems in the Mine Area

Shifting Cultivation (Tavy)

Shifting cultivation (Tavy) is found on upland soils at the edge of forested areas. Shifting cultivation is the mainstay of traditional farming systems over vast areas of the tropics and subtropics. The term shifting cultivation refers to a farming or agricultural system in which land under natural vegetation is cleared, cropped with agricultural crops for a few years (cropping period) and then left untended while natural vegetation regenerates (fallow period). The fallow period is usually several times longer than the cropping period. The length of the fallow period is critical to the sustainability of this agricultural system (Nair 1993). It is generally

accepted that traditional shifting cultivation systems with adequately long fallow periods is a sound agricultural system both ecologically and socially. In this system most of the soil nutrients are stored in the vegetation biomass and topsoil and are held in a closed soil-forest nutrient cycle. Clearing, burning and cropping disrupts this closed nutrient cycle. Exchange nutrients, available phosphorus and pH all increase after clearing and burning but only temporarily. Afterwards soil fertility is depleted due to nutrient uptake by plants, leaching, mineralization, increased soil biological activity, erosion losses and phosphorus fixation. There can also be changes in the physical conditions of the soil after cropping (Nye and Greenland 1960).

Land suitability assessment for shifting cultivation is problematic since the sustainability of this agricultural system is dependant upon the nutrient capital held in the forest biomass and length of the fallow period. Factors used to assess land suitability for shifting cultivation are impediments to root growth, plant toxicities, soil nutrient holding capacity, erosion and topography.

Rain Fed (tanety) Agriculture

Rain fed (tanety) agriculture is found on a comparatively small scale around wetland areas. Agricultural inputs in this system include small scale irrigation and perhaps some soil amendments such as manure or fertilizer. Factors used to assess land suitability for rain fed agriculture are soil acidity, plant toxicities, ability of soil to hold nutrients, erosion and topography.

Wetland Rice Cultivation

Wetland rice cultivation is found in poorly drained wetland areas. Agricultural inputs to this system may include water and soil management. Factors used to assess land suitability for wetland rice cultivation are soil wetness and soil acidity.

3.2.4.2 Land Suitability Ratings of Mine Soils

Ferricrete Soils

Ferricrete soils are located on the plateaus in the mine study area. These soils have a characteristic indurated iron oxide-enriched crust that contains varying concentrations of silica, aluminum, and titanium. These soils have a low pH (soil pH 3.6 to 5.2) and low CEC (4 to 22 meq/100g) which very severely limit crop production. Agriculture land suitability is permanently non suitable due to the shallow rooting on ferricrete soils as well as the suspected aluminum toxicity and nickel and cobalt phytotoxicity (Table 3.1-3). These soils do not even support low input shifting cultivation.

Pisolite Soils

Pisolite soils are located on lower variable slopes in the mine study area. These soils can contain a range of concretions and broken cuirasses. An enriched clay layer can often be found under the concreted horizon. These soils have a low pH (soil pH 3.6 to 4.6) and low CEC (4 to 14 meq/100g) which very severely limit crop production. Agriculture land suitability is currently non suitable for continuous agricultural production due to the soil pH, impediments to rooting, low nutrient status, topography, erosion as well as the suspected aluminum toxicity (Table 3.1-3). Agriculture land suitability is marginally suited for shifting cultivation.

Red/Yellow Ferrilitic Soils

Red/Yellow Ferrilitic soils were generally located topographic lower slope position. These soils have fewer concretions than pisolite soils. These soils have a low pH (Soil pH 3.6 to 4.5) and low to moderate CEC (7 to 18 meq/100g) which severely limit crop production. Agriculture land suitability is currently marginally suitable for continuous agricultural production and shifting cultivation due to the soil pH, topography, erosion as well as the suspected aluminum toxicity (Table 3.1-3).

Organic Soils

Organic soils (Histosols) are poorly to very poorly drained soils that have developed from accumulated organic material. These soils are acidic and of low in base saturation. These soils are marginally suited to wetland rice cultivation due to excess water and acidity (Table 3.1-3).

Table 3.1-3 Agricultural Suitability of Soil Types

Soil Type	Agriculture Land Suitability Class	Limitations	
		Soil	Topography
armoured ferricrete	permanently non suitable (N2)	soil acidity, soil nutrients, nickel and cobalt phytotoxicity, rooting depth	
pisolites (soils containing gravel-like concretions)	currently non suitable (N1) to marginally suitable (S1tefa)	soil acidity, soil fertility	topography (steep slopes), erosion
red/yellow ferrilitic soils	marginally suitable (S1tea)	soil acidity	topography (steep slopes), erosion
organic soils	marginally suitable (S1w)	soil wetness, soil acidity	

3.3 SLURRY PIPELINE

Soil baseline data were collected in conjunction with the vegetation investigations of the proposed slurry pipeline route (Figure 3.1-2). The field program had three objectives:

- to describe some of the soil types along the pipeline route;
- to develop relationships between soil, topography and vegetation; and
- to identify potential soil issues during pipeline construction.

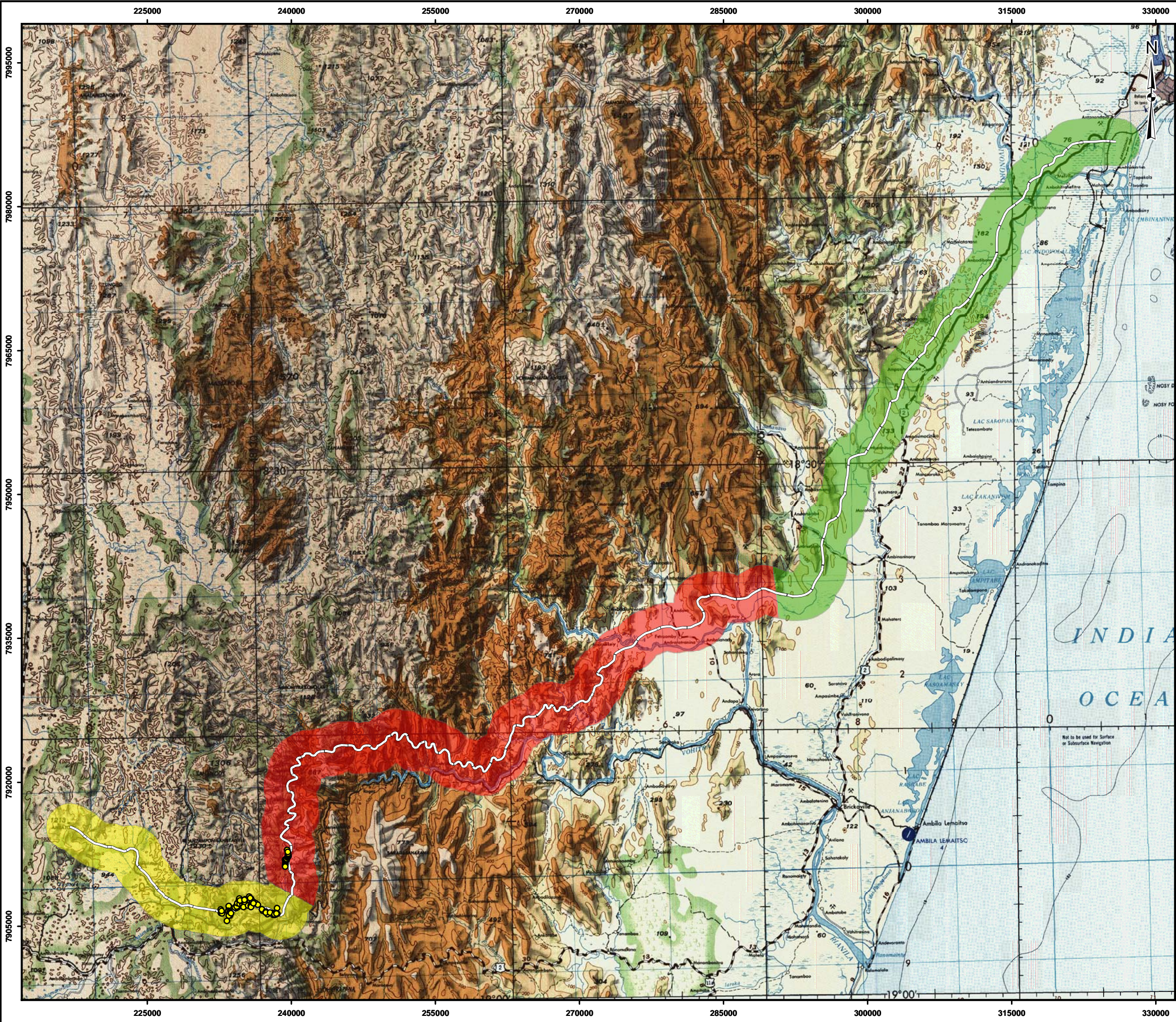
Three transects were studied along the slurry pipeline route (Figure 3.1-2). Slopes in the vicinity of the three transects were very steep (from 30 to 75%) and soils were developed from heavy weathering of granitic and gneiss parent material. Typical of tropical soils, the majority of soil nutrients are contained in the surface organic material, and the soils are sensitive to water erosion due to the steep slopes.

The first transect was located in the forested fragments on the western portion of the route (forest transect, Photograph 3.1-6). The other two transects were located in areas with more agricultural land use and anthropogenic impacts (Akondromorona transect Photograph 3.1-7 and Ambohimananarivo transect Photograph 3.1-8).

In general, soils along the pipeline route followed a relatively predictable pattern. On slope crests, Oxisols were found, at midslope positions soils were generally Ultisols and at the toe of slopes and in depressions, the soils were either Histosols or Oxisols, depending on drainage. Characteristics of these soils are summarized in Table 3.1-4.

In the western part of the pipeline, the soils have developed on heavily weathered cretaceous rock (Delbos 1961) consisting mostly of gneiss, migmatite, granite and migmatic granites. Deep soils have developed on the easily weathered gneiss, while soils developed on granite tend to be thinner. At some locations, erosional processes have occurred more recently and soils were classified as Entisols.

I:/2003/03-1322/03-1322-172/lrxd/Soils/Fig3.1-2_Soils_landuse.mxd



LEGEND

● SOIL INSPECTION POINT

— PROPOSED SLURRY PIPELINE ROUTE

LAND USE TYPE

■ CORRIDOR ZONE, INCLUDING TOROTOROFOTSY WETLANDS

■ TAVY ZONE WITH FOREST PATCHES

■ COASTAL ZONE WITH TAVY, AGROFORESTRY SYSTEMS, RAVINALA FORESTS AND GRASSLANDS

REFERENCE

Datum: WGS 84 Projection: UTM Zone 39S

7.5 0 7.5 15

SCALE 1:400,000 KILOMETRES


PROJECT	AMBATOVY PROJECT		
TITLE	SLURRY PIPELINE SOIL INSPECTION POINTS AND ECOREGIONS		
	PROJECT No.	03-1322-172.6300	SCALE AS SHOWN
	DESIGN	MZ 12 May 2005	REV. 0
	GIS	TN 24 Nov. 2005	
	CHECK	GJ 10 Feb. 2006	
	REVIEW	DM 10 Feb. 2006	

FIGURE: 3.1-2

Table 3.1-4 Summary of Pipeline Soil Characteristics

Slope Position	Soil Type	Soil characteristics
summit (crest)	Ferrilitic Soils – typical blocky structure (Oxisols)	soil has a “good” blocky structure; soil is chemically rich due to enrichment by bases and minerals (mica); soil cohesion is weak to medium
mid slope	strongly Altered or changed Ferrilitic soils (Ultisols)	soil horizon with weak cohesion, low and weak structure; soil aggregates are porous; primary minerals are more or less altered (disappeared)
base of slope (depressions)	poorly developed Hydromorphic (Histosols) soils	soils are more or less rich in altered minerals; horizons have formed from valley alluvium; soils are sandy or silty with low clay content; soils have concretions

In general, the soils of the three transects had similar soil chemical properties. The soils are low in nutrients and acidic (pH less than 5.5; Volume I-3.1, Attachment 4 Soil Chemistry). In some soils, metal toxicities could develop due to very low pH (i.e., less than 4.5). Most soils had low nitrogen and phosphorus levels, low cation exchange capacity and base saturation and high aluminum contents. In general, soil parameters increase from crest to lower slope to depression as sediments and leachable nutrients are transported down slope.

There were some differences between soil organic matter (OM) in the three transects. In the Forest Transect, OM content ranged from 4.6 to 6.3% on the slopes and greater than 30% in the low lying organic soils. In the Akondromorona Transect, OM content was low, ranging from 0.3 to 4.8%. In the Ambohimanarivo Transect, Organic matter content was similar to the forest transect (6.3 to 7.8%).

3.4 PROCESS PLANT AND TAILINGS FACILITY

3.4.1 Overview

The geology near the plant site consists of sandy marine sedimentary materials. Further inland around the tailings facility, the geology consists of continental clayey-sandy sandstone with migmatite (gneiss) at surface. The migmatite formations near the tailings facility have convex relief (low elevation hills and hilltops) separated by well drained valleys (Randriamboavonjy, J., 2005: pers. Comm.).



Photograph 3.1-6 Typical Vegetation and Topography in the Forest Transect



Photograph 3.1-7 General Overview of the Akondromorona Transect



Photograph 3.1-8 General Overview of the Ambohimamarivo Transect

The coastal area near Tamatave has a warm and humid climate with an average annual rainfall of over 3,000 mm in Toamasina and an average temperature of 24°C (Kilian 1968; see also Volume I, Section 4.1). These climatic conditions in association with the area geology, have created podzolization in sandy soils near the coast (plant site) and ferrallization on the migmatite rock further inland (tailings area).

At the crest of convex slopes, ferrilitic soils (oxisols) are typically found. Ferrilitic soils have a sandy-clayey textured granular humus horizon with a polyhedral structure, overlying a sandy-clayey to clayey-sandy textured B horizon with a polyhedral structure. The entire soil profile is rich in quartz and red or yellow in colour.

On upper slope positions, ferrilitic soils (ultisols) are typically present. Ultisols have an underlying clay rich B horizon with a polyhedric structure containing mica flakes. Mid-slope positions usually are ferrilitic soils (ultisols) with a humus horizon directly overlying a loose eluvial horizon rich in primary minerals such as mica. These soils are very susceptible to erosion.

Since tailings area soils are formed on migmatite parent materials, they are naturally acidic, low in nutrients and well drained (on upper slopes). The development of these soils for an agriculture land use would require ameliorating the acidity (liming), fertilization to correct for nutrient deficiencies and good erosion protection.

Soils in the alluvial depressions are hydromorphic soils (Histosols) with some surficial peat accumulation and gleying in the underlying clay rich mineral horizon. These soils are also nutrient poor. These soils are suitable for rice paddy production when nutrient deficiencies are addressed through fertilization.

3.4.2 Process Plant

The process plant is located on the east coast of Madagascar just south of Toamasina, in an area of flat coastal topography dominated by beach ridges.

Incidental soil information has been collected as part of the geotechnical investigations carried out by SNC Lavalin and Geopractica (2004). Soils in the area are developed on stabilized dune sand. In the low lying areas, humic material has accumulated, and soil horizons showed evidence of reduction processes which indicate that the soil is at least periodically saturated with water. The upper landscape positions (Photograph 3.1-9) were well to rapidly drained, with a heavily oxidized B horizon. From the description contained in Geopractica (2004) and the attached photographs, it is likely that these soils are Entisols.

Soils in the process plant area are high in sand and if disturbed would be highly susceptible to wind and water erosion (Photograph 3.1-10).

The sandy soils in the process plant area are generally unsuitable for reclamation due to the coarse texture. However, the A horizons in the low lying areas enriched with organic material may be useful as a reclamation material. This material could be salvaged and used to reclaim temporary disturbances associated with the construction of the processing plant.



**Photograph 3.1-9 Organic Material Accumulation in Low Lying Areas of the
Plant Site (Geopractica 2004)**



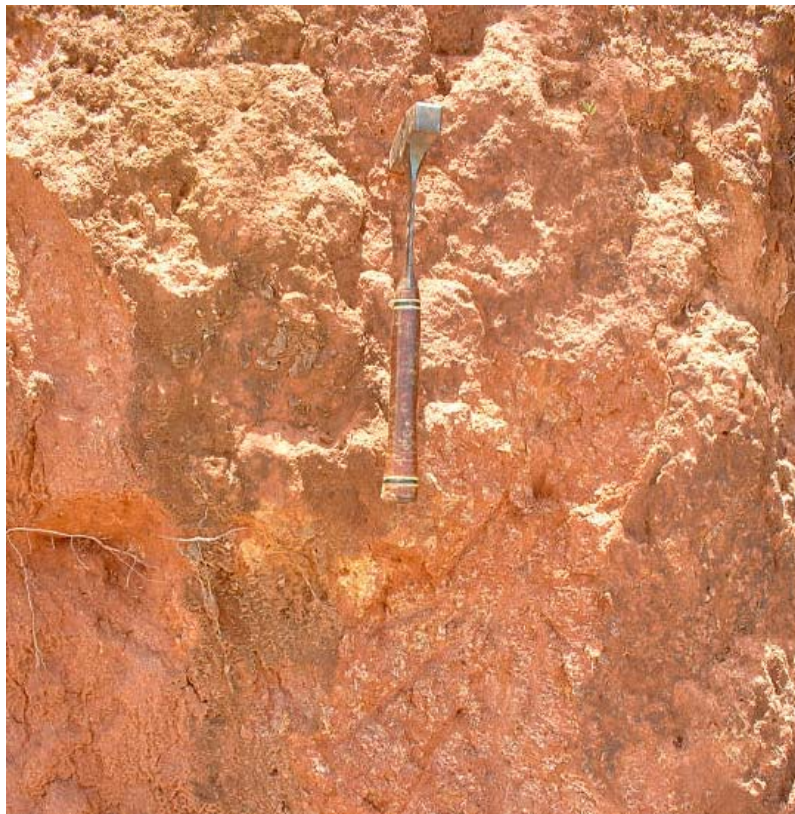
Photograph 3.1-10 Soil Development in the Sand (Geopractica 2004)
(Note heavily oxidized sand in the B horizon)

3.4.3 Tailings Facility

Knight Piesold (2004) noted that the soils in the upper valley area were derived from heavily weathered granite rock (Photographs 3.1-11 and 3.1-12). The soil surface was described as a silty-clayey sand. These soils are likely to be nutrient poor, with the organic material on the surface containing the majority of the soil nutrients. In general, these soils are vulnerable to erosion.



Photograph 3.1-11 Side Cut in Tailings Area (Knight Piesold 2004)



Photograph 3.1-12 Close-up of Weathered Granite in Tailings Area (Knight Piesold 2004)

- soft mottled clays that change irreversibly to hardpans or indurated crusts on exposure to wetting and drying; and
- concretions or nodules in a matrix of consolidated and unconsolidated materials.

3.2 MINE SITE

3.2.1 Soil Classification

Field data on over 80 plots along 6 transects were collected at the mine site on representative soil catenas (Figure 3.1-1). Soil and vegetation mapping was undertaken concurrently to allow correlation between soil and vegetation types.

Four major soil types were mapped from the field program (Figure 3.1-1) and are summarized below.

Armoured Ferricrete soils (Figure 3.1-1; Photographs 3.1-1 and 3.1-2) were observed on topographic plateaus with a hard, rock-like surface layer. These soils are classified as Entisols (generally Lithic Haplu-brepts and Lithic Ustorthents) and Oxisols (generally Typic Acrohumox) under the USDA system.

Pisolite soils (Figure 3.1-1; Photographs 3.1-3 and 3.1-4) were generally located on lower topographic positions than Ferricrete soils. Pisolites can contain a range of concretions and broken cuirasses depending on slope position and other soil forming factors. An enriched clay layer can often be found under the concreted horizon and these soils were generally classified as Oxisols (Haploorthox and Acrorthox) under the USDA system.

Red/Yellow Ferrilitic soils (Figure 3.1-1; Photograph 3.1-5) were generally located in topographic lower slope positions. These soils have fewer concretions and were classified as Ultisols (Typic Paleudults) or as Oxisols (Oxic Dystropepts) under the USDA system.

Organic soils (Figure 3.1-1) were located in depressions. They are developed on organic parent materials, are acidic and have low base saturation. These soils are classified as Histosols (Organic Hydromorpha) under the USDA system.

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4.1 PERSONAL COMMUNICATIONS

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APPENDIX 3.1

ATTACHMENT 1

SOIL DESCRIPTIONS: MINE SITE

Soil Pit T1 – Lower Slope Topographic Position

Location : Mokaranana

18 51 36.6

48 20 34.1

Vegetation : casava, sugar cane, corn, manioc, sweet potatoes

Topography : 25% slope (Lower slope)

Soil Type : ‘sol ferrallitique rouge’ (oxisol)

Samples Soil Pits : T11, T12

Description :

Depth - 0-15 cm :

Colour – Red Brown

Texture – Silty Clay Loam

Structure – Friable, granular, Very Porous

Rooting – Good Rooting

Cohesiveness – Weak

Gradual Transition with lower horizon

Depth - 15-95 cm :

Colour – Red

Structure – Blocky at top of horizon more marked at base

Cohesiveness – Medium

Rooting – Medium to Good

Porosity – Moderately Porous

Soil Pit T2 - Crest Topographic Position

Location : Mokaranana

18 51 37.0

48 20 29.1

Vegetation : *Dalbergia, Chrysophyllum, Ravensara* (9m de hauteur)

Topography : Nil Slope

Soil Type : ‘sol ferrallitique rouge brun remanié’ (oxisol)

Samples Soil : T21, T22

Description :

Depth - 0-5 cm : Matted Organic Litter – fine and medium roots

Depth - 5-20 cm : A horizon

Colour – Brown

Texture – Silty Clay Loam

Consistence A – Friable, Granular

Rooting – Good

Comments – Stone Line present, Abrupt Transition with lower horizon

Depth - 20-85 cm : B horizon

Colour B – Reddish Brown on top of horizon - brownish red at base of horizon

Texture – Clayey

Cohesiveness – Medium

Structure – Blocky

Rooting – Good at top of horizon – Medium at base of horizon

Comments – Stoneline to 55 cm

Soil Pit G - Inclined Slope

Location : Berano Crossing

UTM Coordinates :

0216943

7915445

Vegetation : *Protorhus ditimena*, *Diospyros*, *Canarium*, *Symphonia*, *Leptolaena* (10-12m)

Topography : 45% Slope

Soil type : 'sol ferrallitique rajeuni' (ultisol)

Samples : G1, G2, G3

Description :

Depth - 0-10 cm : Organic Layer – Matted with roots

Depth - 10-30 cm : A horizon

Colour – Yellow brown

Structure – Granular and friablegrelu et grumeleux,

Clay – Clayey

Cohesiveness – Weak

Nodules – purplish and black on surface

Rooting – Abundant with large roots at the base

Comments – Gradual boundary change

Depth - 30-60 cm :

Colour – Reddish yellow

Structure – Blocky

Texture – Clayey

Comments – Rock pieces (5cm) in upper portion of horizon

– Gradual boundary Change

Depth - 60-102 cm : B2 horizon

Colour – Reddish yellow

Texture – Clayey to Silty Clay Loam

Structure – Blocky

Cohesive – Medium

Rooting – Weak to Medium

ZONE ANALAMAY

Soil Pit - F4

Location : UTM Coordinates:

0219179
7919937

Topography : 45%

Vegetation : *Sarcolaena*, *Shefflera*, *Eugenia* (filiforme mais haut)

Soil Type : 'sol rouge brunâtre' (oxisol) avec des concrétions et quelques gros morceaux de cuirasse et résidus d'altération.

Samples : F41, F42, F43

Description :

Depth - 0-6 cm :

Litter layer – Color brownish black, Exceptional rooting

Depth - 6-22 cm : A horizon (Humified)

Colour – Brown Red

Texture – Silt Loam to Silty Clay Loam

Structure – Granular on top subangular at base

Rooting – Many fine, medium and large roots

Comments – Abrupt Transition

Depth - 22-60 cm : B1 horizon

Colour – B1 Light brownish red

Texture – Clayey

Structure – Blocky

Rooting – Medium to Good

Cohesiveness – Medium

Porosity – Medium

Comments – Mixture of Armouring and Concretions. Concretions and armouring in state of alteration and range in size from large to small.

Depth - 60-92 cm : B2 horizon

Colour – Reddish

Texture – Loam

Structure – Blocky

Cohesiveness – Medium

Rooting – Some Roots

Comments – Large residual armouring and altered concretions

Soil Pit - Sa2

Location : UTM Coordinates:

0218889

7919914

Topography : Weakly Sloping (15%)

Vegetation : *Sarcolaena*, , *Schefflera*, *Diospyros*, *Protorhus ditimena*, (8m)

Soil Type : 'sol jaune concrétionné et cuirassé' (oxisol)

Samples : Sa21, Sa22

Description :

Depth - 0-5 cm :

Comments – Thin Litter layer, Large Roots at base of horizon, Medium Concretions and Armouring

Depth - 5-20 cm : A horizon

Colour – Yellowish Brown

Consistence – Friable

Texture – Loam

Cohesiveness – Medium to Weak

Rooting – Good

Comments – Abrupt Boundary transition, Armouring and medium sized concretions

Depth - 20-70 cm : B horizon

Colour – Yellow

Structure – Fine Blocky

Texture – Sandy Loam

Rooting – Weak (some roots)

Cohesiveness – Medium

Comments – Not very porous

Soil Pit - Fo:

Location : UTM Coordinates:

0218583

7919673

Topography : Crest (nil slope)

Vegetation : *Sarcolaena*, *Schefflera*, *Eugenia* , *Asteropeia*, *Anthocleista*, *Protorhus ditimena* (8m)

Soil Type : 'sol brun jaune à jaune riche en concrétions' (oxisol)

Samples : F01, F02

Description :

Depth - 0-22 cm : – Thick Litter layer, Abundant roots, concretions at base

Depth - 22-35 cm : A Horizon

Colour – Thick yellowish brown with blackish brown

Texture – Sandy Clay Loam to Sandy loam

Rooting – Good (rooting all sizes)

Structure – Friable Crumb or Granular

Comments – Abrupt boundary transition, Concretions are fine with sandy appearance

Depth - 35-90 cm :

Colour – Yellowish with reddish purple concretions

Texture – Loam

Structure – Blocky

Cohesiveness – Medium

Rooting – Few Fine Roots

Comments – Concretions are reddish purple and anular to subrounded horizon

Soil Pit - Sm (Centre Analamay)

Location : UTM Coordinates:

0218418
7918216

Topography : Gently Sloping (20%)

Vegetation : *Philippia*, fougère, *Dracaena*

Soil Type : 'sol rouge brun concrétionné sans litière car brûlé quelques morceaux de cuirasse':
(ultisol)

Samples : Sm11, Sm12

Description :

Depth - 0-15 cm: Horizon A

Colour – Brownish Red
Texture – Sandy
Rooting – Good (plentiful Roots)
Cohesiveness – Weak
Comments – Concretions, Very Porous

Depth - 15-70 cm :

Colour – Brownish Red
Texture – Loam
Rooting – Medium
Cohesiveness – Medium
Concretions – Fine and Medium

Soil Pit - x1

Location : UTM Coordinates:

0218956
7919079

Topography : 12% slope

Vegetation : *Protorhus ditimena*, *Schefflera* (5m) ; forêt brûlée

Soil Type : 'sol jaune concrétionné' (ultisol)

Samples : x11, x12

Description :

Depth - 0-7 cm : Thin litter layer with root mat

Depth - 7-21 cm : A horizon A

Colour – Brown Red
Texture – Sandy
Rooting – Good
Cohesiveness – Weak
Comments – Concretions 'shot like', fine, rounded and blackish

Depth - 21-85 cm: B horizon

Colour – Yellow with a lot of concretions
Structure – Blocky
Texture – Sandy
Comments – Rooting many fine and medium

Soil Pit - x2

Location : UTM Coordinates:

0218559
7919116

Topography : 15%

Vegetation : *Uapaca*, *Protorhus ditimena*, *Schefflera*, *Symphonia* (7m) ; bordure forêt naturelle

Soil Type : 'sol rouge' (ultisol)

Samples : x21, x22

Description :

Depth - 0-10 cm : Matted with roots with large roots at base of horizon

Depth - 10-22 cm :

Colour – Brownish red

Texture – Sandy Loam

Structure – Friable granular or crumb

Rooting – Good

Comments – Armoured layer at 10 cm, Abrupt to distinct boundary change.

Depth - 22-80 cm : B horizon

Colour – Red Brown

Texture – Sandy Loam

Structure – Blocky with alterations

Cohesiveness – Weak

Rooting – Very few roots

Comments – Concretions are fine, black and subrounded

Soil Pit - x3

Location : UTM Coordinates:

0217798

7917498

Topography : strong slope (45%)

Vegetation : *Uapaca*, *Protorhus ditimena*, *Schefflera*, *Symphonia* (7m) ; forêt naturelle modifiée

Soil Type : 'sol rouge concrétionné' (ultisol)

Samples : x31, x32

Description :

Depth - 0-6 cm : Litter matted with fine, medium and large roots

Depth - 6-21 cm : A Horizon

Colour – Red

Texture – Sandy Loam

Cohesiveness – weak

Rooting – Good – Roots are fine, medium and large and between concretions

Comments – Abrupt Transition

Depth 21-85 cm : B Horizon

Colour – Dark Red,

Texture – Sandy Loam

Structure – Massive (Continuous)

Rooting – Weak (some medium roots in upper portion of horizon)

Comments – Not very porous, Fine black concretions

Soil Pit - S

Location : UTM Coordinates:

0219979

7917951

Topography : strong slopes (30%)

Vegetation : *Eugenia*, *Symphonia*, *Schefflera*, *Podocarpus*, *Asteropeia*

Soil Type : 'sol ferrallitique rouge jaunâtre' (ultisol)

Samples : S1, S2, S3

Description :

Depth - 0-6 cm: Litter matted with fine roots

Depth - 6-22 cm :

Colour – Brown Red

Texture – Clayey

Structure – Friable Granular or Crumb

Cohesiveness – Weak

Rooting – Exceptional

Boundary Transition – Gradual

Depth - 40-97 cm : B2 horizon B2

Colour – Red

Texture – Sandy Loam

Structure – Blocky

Rooting – Practical absence of roots

Comments – Porous

ZONE AMBATOVY

Soil Pit - V6

Location : UTM Coordinates:

0214525

7912999

Topography : Low Slope - Weak to nil Slope

Vegetation : *Podocarpus*, *Ocotea*, *Weinmannia*, *Ravensara*, *Chrysophyllum*, *Sarcolaena*, *Prothorus ditimena* (18-21m)

Soil Type : 'sol ferrallitique jaune brun' (oxisol)

Samples : V61, V62

Description :

Depth - 0-5 cm : Litter matted with fine roots

Depth - 5-25 cm : A horizon

Colour – Brown Yellow

Texture – Sandy Clay loam

Structure – Friable Granular or Crumb – Block at the base of the horizon

Cohesiveness – Weak

Rooting – Good (fine and medium roots)

Boundary Transition – Gradual

Depth - 25-50 cm : B horizon

Colour – Yellow Brown

Texture – Sandy Clay

Cohesiveness – Weak to Medium

Rooting – Roots rare at base

Boundary Transition – Gradual

Comments – Mix of concretions and altered residual – Red to whitish red

Depth - 50-103 cm :

Colour – Brown Yellow

Texture – Clayey

Structure – Blocky

Cohesiveness – Medium

Comments – No Roots

Soil Pit - V7

Location : UTM Coordinates:

0214258

7912884

Topography : base of steep slope (60%), close to creek

Vegetation : *Ravensara*, *Dalbergia*, *Chrysophyllum* (9-10 m)

Soil Type : 'sol jaune brun sur rouge jaunâtre' (ultisol)

Samples : V71, V72, V73

Description :

Thin Litter Layer

Depth - 0-23 cm : A horizon

Colour – Yellowish Brown

Texture – Sandy loam

Consistency – Friable

Cohesiveness – Medium

Rooting – Presence of medium roots at base of horizon

Depth - 23-40 cm : B1 horizon

Colour – Yellow Brown

Texture – Sandy Clay

Cohesiveness – Slightly strong

Rooting – Weak

Boundary Transition – Gradual

Depth - 40-90 cm : B2 horizon

Texture – Sandy clay (with grains of quartz)

Structure – Massive (Continuous)

Cohesiveness – Medium to Strong

Comments – Not Very Porous

Soil Pit - B6

Location : UTM Coordinates:

0218167
7912504

Topography : 15% (close to summit)

Vegetation : *Schefflera*, *Eugenia*, *Protorhus ditimena*, *Chrysophyllum*, *Ravensara*, *Podocarpus*
(9 10m)

Soil Type : 'sol rouge foncé avec beaucoup de concrétions et de morceaux de cuirasse surtout au niveau A'. Les racines se trouvent entre les concrétions et cuirasses même au niveau de B (10-20cm). (Oxisol).

Samples : B61, B62

Description :

Depth - 0-9 cm : Litter matted with roots

Depth - 9-34 cm : A horizon

Colour – Dark Red
Texture – Sandy Clay Loam
Structure – Blocky (Friable Granular)
Cohesiveness – Medium
Rooting – Abundant fine, medium and large roots
Boundary Transition – Abrupt
Comments – Concretions and armoured pieces

Depth - 34-80 cm : B horizon

Colour – Dark Red
Texture – Loam
Structure – Blocky
Cohesiveness – Medium
Rooting – Fine and Medium roots
Comments – Large concretions and armouring

Soil Pit - B8

Location : UTM Coordinates:

0217976

7912616

Topography : 5-10% (gradual slope)

Vegetation : *Protorhus ditimena*, *Eugenia*, *Symphonia*, *Sarcolaena* (9-10m)

Soil Type : 'sol rouge violacée. (limite des zones de concrétions) grenailles, et cuirasses' : oxisol

Samples : B81, B82

Description :

Depth - 0-13 cm : Litter later matted with roots (Rooting Zone)

Depth - 13-34 cm : A horizon

Colour – Purplish Brown

Texture – Sandy Loam

Rooting – Good

Boundary Transition – Abrupt

Comments – Concretions and Armouring (Large pieces of armouring at base of horizon)

Depth - 34-78 cm : B horizon

Color – Brownish Yellow Red

Texture – Sandy loam

Structure – Blocky

Comments – Concretions and armouring. There are a lot of concretions.

Soil Pit - B11

Location : UTM Coordinates:

0217759

7912568

Topography : gradual (5%) to flat slopes

Vegetation : *Protorhus ditimena*, *Schefflera* , *Dombeya*, *Sarcolaeana* (7-8m)

Soil Type : 'sol jaune concrétionné' (oxisol)

Samples : B111, B112

Description :

Depth - 0-8 cm : litière enchevêtrée de racines, grosses racines à la base.

Depth - 8-30 cm : A horizon

Colour – Yellowish Brown

Texture – Sandy Loam

Rooting – Good

Cohesiveness – Medium

Boundary Transition – Abrupt

Comments – Concretions and large pieces of armouring.

Depth - 30-90 cm : B horizon yellow

Colour – Brown

Texture – Sandy Loam, brun, concrétionné, sablo-limoneux

Structure – Blocky to Subangular Block

Cohesiveness – Slightly Strong

Rooting – Rare

Soil Pit - C3

Location : UTM Coordinates:

0217087

7913379

Topography : 25% - slope

Vegetation : *Protorhus ditimena*, *Asteropeia*, *Sarcolaena* (8-9m)

Soil Type : 'sol rouge violacé' (concrétions moyennes et fines au sommet) : ultisol

Samples : C31, C32, C33

Description :

Depth - 0-15 cm : Litter and exceptional fine, medium and large roots

Depth - 15-25 cm : A horizon

Colour – Red Brown

Texture – Sandy

Rooting – Weak

Comments – Fine Concretions

Depth - 25-50 cm : B horizon

Colour – Brownish Red

Texture – Sandy Loam

Structure – Blocky

Rooting – Average Medium and fine roots

Depth - 50-90 cm : B horizon

Colour – Purplish red

Texture – Sandy Clay Loam

Structure – Blocky to Massive

Rooting – Weak

Comments – Not Very porous

Soil Pit - C6

Location : UTM Coordinates:

0217370

7911861

Topography : (50%), base of slope

Vegetation : *Protorhus ditimena*, *Eugenia*, *Ravensara*, *Sarcolaena*, *Canarium*, *Dalbergia*
(12-13m)

Soil Type : 'sol rouge meuble avec grosse cuirasse' (ultisol)

Samples : C61, C62, C63

Description :

Depth - 0-5 cm : Thin litter layer matted with roots and large pieces of armouring

Depth - 5-20 cm : A horizon A

Colour – Brown Red

Texture – Loam

Structure – Friable Crumb or Granular

Cohesiveness – Weak

Rooting – Good

Boundary Transition – Good

Depth - 20-50 cm B 1 horizon

Colour – Red

Texture – Clayey

Structure – Fine Blocky

Cohesiveness – Weak to Medium

Rooting – Good

Depth - 50-102 cm : B2 horizon

Colour – Red

Texture – Loam

Cohesiveness – Weak

Roots – Rare

Soil Pit - J2

Location : UTM Coordinates:

0216429
7913071

Topography : 30%, mid-slope, moderate slopes (close to camp)

Vegetation : *Eugenia*, *Schefflera*, *Protorhus ditimena* (7-8 m)

Soil Type : 'sol rouge jaunâtre concrétionné' (ultisol)

Samples : J21, J22

Description :

Depth - 0-9 cm : Litter with matted roots (roots medium and large at the base).

Depth - 9-25 cm : A horizon

Colour – Red Brown

Texture – Sandy Loam

Structure – Friable Granular and Crumb

Cohesiveness – Weak

Boundary Transition – Gradual

Comments – A lot of Concretions and 5-10 cm armouring.

Depth - 25-78 cm : B horizon B

Colour – Red

Texture – Loam

Structure – Fine Blocky

Cohesiveness – Medium

Rouge de moins en moins de cuirasses mais des concrétions noires fines. Texture : limon sablo-argileux. Structure polyédrique fine à continue à éclats à la base. Peu poreux. Cohésion moyenne. Très peu de racines mais il existe de racines moyennes à la base.

Soil Pit - W3

Location : UTM Coordinates:

0215607
7913178

Topography : 30% Slope (west facing)

Vegetation : *Eugenia*, *Prothorus ditimena*, *Sarcolaena*, *Ravensara*, *Dalbergia* (12m)

Soil Type : sol rouge foncé profond (ultisol)

Samples : W31, W32, W33

Description :

Depth - 0-25 cm: A horizon

Colour – Brown Red

Structure – Friable Granular and Crumb

Texture – Sandy Clay

Cohesiveness – Weak

Horizon Boundary Transition – Gradual

Comments – Concretions and powdery armouring, Porous (psuedosandy).

Depth - 25-70 cm : B1 horizon

Colour – Dark Red

Texture – Sandy Loam

Structure – Blocky

Cohesiveness – Weak

Rooting – Weak

Horizon Boundary Transition – Gradual

Comments – Porous and pseudosandy

Depth - 70-120 cm : B2 horizon

Colour – Purplish Red (Yellow – Dry color)

Texture – Sandy Loam

Structure – Blocky

Cohesion – Strong

Rooting – Absent

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APPENDIX 3.1

ATTACHMENT 2

**MINE SOIL ANALYTICAL PROPERTIES
(2004 SOIL TRANSECTS)**

Tableau 1 Résultats des analyses physico-chimiques des sols

Sigle	pH (eau)	pH (KCl)	Conductivité mmho/cm	C%	N%	P (ppm)	P (total) (ppm)	Bases échangeables (meq/100g)				CEC mé	S meq	V%	Al3+ méq/100g	H+ méq/100g	Granulométrie %					
								Ca	Mg	Na	K						Argile	Limon	Sable	CECE	Sc	m
B 11	4.6	4.33	220	4.82	0.329	15.2	26.1	0.605	0.45	0.434	0.218	18.2	1.707	9.37	1.04	1.76	30	41	29	4.507	15.4	23.1
B 12	4.49	4.11	195					0.014	0.208	0.282	0.183	5.3	0.687	12.96	0.21	0.52	41	38	21	1.417	13.8	14.8
B 13	5.43	5.15	72					0.09	0.016	0.26	0.023	2.2	0.389	17.68	0.104	0.004	16	57	27	0.497	5	20.9
B 81	3.72	3.6	202	4.1	0.189	31.1	37.3	0.019	0.283	0.434	0.115	9.8	0.851	8.68	0.208	1.14	6	15	79	2.199	13.7	9.45
B 82	4.6	4.22	250					0.017	0.089	0.317	0.135	7.4	0.558	7.54	0.364	0.554	15	27	58	1.476	12.4	24.6
B 61	4.05	3.74	95	5.19	0.273	22.2	31.5	0.011	0.25	0.126	0.087	4.2	0.474	11.28	0.52	0.728	15	26	59	1.722	29.7	30.2
B 62	5.39	5.11	175					0.095	0.183	0.565	0.123	6.3	0.966	15.33	0.052	0.164	21	31	48	1.182	3.4	4.4
B 111	4.61	4.35	160	6.38	0.343	37.9	48.6	0.255	0.266	0.26	0.164	14.4	0.945	6.56	1.82	2.6	11	25	64	5.365	30.7	33.9
B 112	5.8	5.39	175					0.255	0.266	0.26	0.164	14.4	0.777	29.88	1.82	2.6	11	25	64	5.197	30.7	35
C 31	3.81	3.76	42	3.65	0.168	10	27.3	0.01	0.056	0.021	0.038	6.4	0.125	1.95	0.52	0.676	6	9	85	1.321	18.7	39.4
C 32	4.8	4.5	50					0.012	0.046	0.091	0.135	7.7	0.284	3.68	0.208	0.278	17	34	49	0.77	6.3	27
C 33	3.96	3.83	54					0.008	0.03	0.039	0.023	1.4	0.1	7.14	0	0	15	28	57	0.1	0	0
C 61	4.71	4.33	100	3.31	0.217	40	43.5	0.016	0.208	0.1	0.069	8.6	0.393	4.57	0.26	0.442	19	31	50	1.095	8.2	23.7
C 62	5.9	5.41	120					0.9	0.044	0.347	0.059	2.9	0.54	18.62	0.052	0.056	32	37	31	0.648	3.7	8
C 63	5.3	5.1	25					0.125	0.021	0.26	0.018	1.6	0.424	26.5	0	0	22	33	45	0.424	0	0
C 71	4.9	4.5	139	3.14	0.231	3.3	18.7	0.035	0.341	0.069	0.112	6.7	0.557	8.31	0.16	0.156	25	28	47	0.873	4.7	18.3
C 72	4.86	4.58	74					0.135	0.09	0.434	0.077	6.3	0.736	11.68	0.052	0.056	41	37	22	0.844	1.7	6.2
C 73	4.81	4.4	33					0.008	0.04	0.026	0.023	3.3	0.097	2.93	0	0.054	18	43	39	0.151	1.6	0
C 81	4.4	4.21	137	4.43	0.105	13	25.9	0.1	0.086	0.391	0.105	9.6	0.681	7.1	1.19	1.72	28	19	53	3.591	30.3	33.1
C 82	4.48	4.19	35					0.01	0.058	0.082	0.025	6.5	0.175	2.69	0.312	0.23	41	25	34	0.717	8.2	43.5
C 83	4.5	4.18	30					0.011	0.032	0.052	0.015	2.1	0.11	5.23	0.052	0	27	26	47	0.162	2.5	32.1
F 01	4.18	4.03	112	6.97	0.182	23.3	31.2	0.007	0.166	0.147	0.105	19.9	0.425	2.13	1.92	2.67	17	11	72	5.015	23.1	38.3
F 02	4.7	4.36	30					0.007	0.045	0.039	0.028	4.5	0.119	2.64	0.104	0.112	18	31	51	0.335	4.8	31
F 21	4.6	4.27	165	3.75	0.259	11.1	26.3	0.24	0.103	0.078	0.46	7.7	0.881	11.44	0.1	0.208	30	27	43	1.189	4	8.4
F 22	4.3	4.07	41					0.015	0.3	0.039	0.179	6.9	0.533	7.72	0.416	0.39	50	23	27	1.339	11.7	31.1
F 23	4.11	3.96	20					0.006	0.091	0.03	0.066	4.7	0.193	4.11	0.05	0.052	54	31	15	0.295	2.2	17
F 41	4.8	4.48	68	3.27	0.28	14.4	25.8	2.4	0.766	0.105	0.08	2.2	3.411	15.5	0.156	0.222	27	21	52	3.789	17.2	4.12
F 42	4.54	4.35	30					0.008	0.052	0.026	0.053	3.8	0.139	3.66	0.156	0.006	40	23	37	0.301	4.3	51.8
F 43	4.56	4.28	24					0.016	0.091	0.026	0.02	4.3	0.153	3.55	0	0	24	25	51	0.153	0	0
E 11	4.91	4.59	39	2.46	0.112	5.4	7.9	0.14	0.045	0.608	0.041	5.6	0.834	14.89	0.72	2.52	13	11	76	4.074	22.14	17.7
E 12	5.2	4.88	78					0.014	0.041	0.1	0.023	4.8	0.178	3.71	0.052	0.002	13	35	52	0.232	1.1	22.4
E 13	5.38	5.08	71					0.09	0.133	0.304	0.031	1.4	0.558	39.85	0.052	0.056	5	13	82	0.666	7.7	7.8
J 11	4.9	4.51	76	1.93	0.217	1.1	6.5	0.031	0.133	0.204	0.079	8.9	0.447	5.02	0.156	0.384	14	25	61	0.987	6	15.8
J 12	4.68	4.25	33					0.021	0.05	0.126	0.079	5.2	0.276	5.31	0.052	0.002	31	28	41	0.33	1.03	15.7
J 21	5.12	4.81	123	3.78	0.175	6.7	12.3	0.123	0.258	0.365	0.061	8.1	0.807	9.96	0.104	0.22	10	22	68	1.131	4	9.2
J 22	5.25	5.04	38					0.15	0.041	0.434	0.025	3.5	0.556	15.88	0.052	0.11	22	29	49	0.718	4.6	7.3
J 41	4.2	4.07	190	4	0.252	2.2	8.4	0.93	0.191	0.391	0.118	13.8	0.93	6.74	0.52	0.77	26	33	41	2.22	9.3	23.4

Tableau 1 Résultats des analyses physico-chimiques des sols (continued)

Sigle	pH (eau)	pH (KCl)	Conductivité mmho/cm	C%	N%	P (ppm)	P (total) (ppm)	Bases échangeables (meq/100g)				CEC mé	S meq	V%	Al3+ méq/100g	H+ méq/100g	Granulométrie %					
								Ca	Mg	Na	K						Argile	Limon	Sable	CECE	Sc	m
J 42	4.96	4.52	150					0.014	0.037	0.317	0.046	4.3	0.414	9.63	0.052	0.002	11	20	69	0.468	1.25	11
J 43	4.31	3.85	20					0.008	0.023	0.021	0.01	1	0.062	6.2	0	0	7	12	81	0.062	0	0
J 51	4.62	4.3	100	3.06	0.21	24.9	35.8	0.085	0.094	0.26	0.087	7.6	0.526	6.92	0.88	1.22	32	21	47	2.626	27.6	33.5
J 52	4.48	4.45	50					0.003	0.023	0.16	0.043	5.7	0.229	4.02	0.156	0.006	59	18	23	0.385	2.8	40.5
J 53	5	4.68	52					0.011	0.027	0.147	0.038	2.6	0.223	8.57	0	0	9	8	83	0.223	0	0
J 61	3.78	3.64	86	3.31	0.189	11.9	20.1	0.011	0.076	0.113	0.038	9.5	0.238	2.51	1.61	2.18	13	18	69	4.028	39.9	40
J 62	5.19	5	106					0.145	0.241	0.478	0.036	1.8	0.9	50	0.052	0.056	8	31	61	1.008	6	5.1
J 71	4.21	4	100	5.56	0.273	17.3	28.4	0.002	0.097	0.152	0.025	22.6	0.276	1.22	2.13	2.83	29	16	55	5.236	21.9	40.7
J 72	4.92	4.52	82					0.005	0.091	0.139	0.082	6.8	0.317	4.61	0.26	0.28	18	22	60	0.857	7.9	30.3
J 81	4.87	4.44	142	4.09	0.252	1.1	5.4	0.016	0.108	0.343	0.079	6.3	0.546	8.7	0.312	0.66	26	4	70	1.518	15.4	20.5
J 82	5.02	4.65	104					0.015	0.037	0.404	0.123	6.9	0.579	8.4	0.052	0.002	9	16	75	0.633	1	8.2
R 1	4.92	4.6	144	8.51	0.7	1.1	6.3	1.29	0.7	0.695	0.333	48.1	3.018	6.27	0.52	1.47	8	32	60	5.008	4.1	10.4
R 2	4.54	4.32	110					1.74	0.925	0.565	0.092	58.1	3.322	5.72	0.41	0.99	10	30	60	4.732	2.4	8.7
S 1	4.26	4.05	131	4.01	0.294	26.7	36.5	0.014	0.141	0.091	0.117	10.9	0.363	3.33	0.832	1.06	33	31	36	2.255	17.4	36.9
S 2	5.05	4.87	47					0.17	0.037	0.26	0.043	4	0.51	12.75	0.156	0.168	31	27	42	0.834	8.1	18.7
S 3	4.56	4.21	30					0.012	0.108	0.165	0.023	3.5	0.308	8.8	0.052	0.002	13	21	66	0.362	1.5	14.4
Sa 21	5.5	5.21	143	5.02	0.231	5.4	10.8	0.125	0.116	0.521	0.138	9.7	0.9	9.28	0.52	0.88	25	23	52	2.3	14.4	22.6
Sa 22	4.75	4.3	38					0.014	0.035	0.156	0.046	4.5	0.251	5.58	0.104	0.058	16	26	58	0.413	3.6	25.2
Sm 1	4.83	4.47	27	3.08	0.161	1.1	5.8	0.013	0.066	0.156	0.038	6.7	0.273	4.1	0.416	0.448	7	15	78	1.137	12.9	36.6
Sm 2	4.54	4.29	375					0.011	0.191	0.652	0.082	6.5	0.936	14.4	0.208	0.386	25	30	45	1.53	9.1	13.6
Sv 1	4.06	3.83	65	2.91	0.091	4.3	8.3	0.12	0.094	0.391	0.087	8	0.692	8.65	0.104	0.868	6	11	83	1.664	12.1	6.2
Sv 2	3.85	3.7	32					0.016	0.083	0.139	0.03	6.2	0.268	4.32	0.052	0.322	7	7	86	0.642	6	8.1
V 11	4.6	4.3	95	2.62	0.14	20.6	31.4	0.645	0.258	0.347	0.094	9.4	1.344	14.3	0.26	0.87	5	7	88	1.474	12.1	17.6
V 12	3.9	3.79	28					0.011	0.034	0.017	0.017	3.2	0.079	2.47	0.05	0.156	8	11	81	0.285	6.4	17.5
V 21	3.75	3.61	65	3.07	0.196	6.7	15.8	0.016	0.084	0.026	0.043	5.8	0.169	2.91	0.36	0.57	8	11	81	1.099	16	32.7
V 22	3.89	3.66	48					0.009	0.025	0.026	0.028	2.1	0.088	4.2	0.1	0	8	33	59	0.188	4.8	53.2
V 23	3.8	3.69	87					0.006	0.02	0.017	0.025	1.7	0.068	4	0	0	9	14	77	0.068	0	0
V 61	5.5	5.1	225	2.78	0.182	40.1	43.2	0.073	0.775	0.182	0.243	12.3	1.273	10.35	0.052	0.11	16	25	69	1.435	1.3	3.6
V 62	4.42	4.15	53					0.064	0.191	0.039	0.046	2.6	0.34	13.1	0.05	0.104	34	21	45	0.494	6	10.1
V 71	4.4	4.17	102	1.78	0.049	28.9	52.6	0.083	0.775	0.052	0.461	7.1	1.371	19.31	0.676	0.88	16	21	63	2.927	21.9	23.1
V 72	4.46	4.01	30					0.02	0.475	0.039	0.143	2.8	0.677	24.18	1.14	0.936	29	16	55	2.753	74.1	41.4
V 73	4.45	4.1	18					0.009	0.491	0.034	0.043	4.1	0.577	14.1	0.98	2.17	32	21	47	3.727	28	26.3
W 21	4.55	4.31	225	4.11	0.357	3.3	10.3	0.23	0.191	0.391	0.231	7.3	1.043	14.29	0.57	0.88	12	19	69	2.493	19.8	22.9
W 22	4.39	4.13	92					0.017	0.094	0.195	0.123	5.7	0.429	7.53	0.052	0.11	14	25	61	0.591	2.8	8.8
W 23	5.1	4.85	80					0.014	0.041	0.182	0.033	5.5	0.27	4.9	0	0	13	45	42	0.27	0	0
W 31	4.15	3.89	60	1.42	0.133	2.2	7.5	0.115	0.038	0.213	0.043	9.9	0.409	4.13	0.62	0.83	30	27	43	1.859	14.6	33.3

Tableau 1 Résultats des analyses physico-chimiques des sols (continued)

Sigle	pH (eau)	pH (KCl)	Conductivité mmho/cm	C%	N%	P (ppm)	P (total) (ppm)	Bases échangeables (meq/100g)				CEC mé	S meq	V%	Al3+ méq/100g	H+ méq/100g	Granulométrie %					
								Ca	Mg	Na	K						Argile	Limon	Sable	CECE	Sc	m
W 32	3.81	3.69	117					0.008	0.033	0.091	0.02	2	0.152	7.6	0.104	0.004	6	25	69	0.26	5.4	40
W 33	4.75	4.53	100					0.125	0.017	2.17	0.02	2.5	2.332	93.28	0	0	6	27	67	2.332	0	0
W 51	4.36	4.12	135	3.12	0.161	11.9	18.3	0.155	0.083	0.347	0.107	6.9	0.692	10	0.7	1.16	23	21	56	1.552	26.9	45.1
W 52	4.3	4.11	57					0.016	0.037	0.139	0.038	4	0.23	5.75	0.104	0.004	25	10	65	0.338	2.7	30.7
W 53	4.87	4.51	70					0.012	0.019	0.091	0.058	2.1	0.18	8.57	0	0	7	18	75	0.18	0	0
W 54	4.55	4.22	27					0.009	0.008	0.03	0.007	2.5	0.054	2.16	0	0	15	50	35	0.054	0	0
X 11	4.3	4.01	28	6.76	0.154	18.9	26.7	0.038	0.225	0.026	0.025	4	0.314	7.85	0.16	0	6	15	79	0.474	4	33.7
X 12	4.9	4.48	23					0.009	0.037	0.017	0.028	2.5	0.091	3.64	0	0	6	9	85	0.091	0	0
X 21	4.69	4.19	65	4.9	0.231	10	20.7	0.023	0.125	0.191	0.066	8.5	0.405	4.76	0.42	1.5	13	14	73	2.325	22.6	18.1
X 22	4.95	4.5	31					0.009	0.045	0.06	0.015	2.3	0.129	5.6	0.052	0.002	6	21	73	0.183	2.3	28.4
X 31	4.5	4.12	31	4.65	0.287	10	18.6	0.012	0.108	0.039	0.051	4.1	0.21	5.12	0.364	0.34	12	17	71	0.914	17.1	39.8
X 32	4.62	4.3	22					0.009	0.038	0.026	0.023	2.8	0.096	3.43	0	0	14	31	55	0.096	0	0
T11	5.41	5.09	90	4.87	0.357	24.3	41.5	4.3	0.34	0.139	0.384	9.9	5.163	52.5	0.458	1.26	35	45	20	6.881	17.4	6.6
T12	4.72	4.53	58					0.64	0.275	0.091	0.256	3.3	1.262	38.24	0.26	0.28	40	35	25	1.802	16.4	14.4
G1	4.65	4.5	46	6.25	0.329	10.2	16.3	0.22	0.05	0.169	0.128	10.8	0.567	5.25	1.56	2.22	28	38	34	4.347	35	35.9
G2	4.8	4.59	24					0.14	0.083	0.113	0.038	4.3	0.374	8.7	0.26	0.49	25	30	45	1.124	17.4	23.1
G3	4.86	4.55	15					0.15	0.058	0.034	0.028	2.2	0.27	12.27	0.104	0.058	32	43	25	0.432	7.4	24.1
T21	4.85	4.6	55	3.32	0.238	21.2	36.7	0.51	0.283	0.1	0.256	5	1.149	22.98	0.572	0.88	22	46	32	2.601	29	22
T22	4.93	4.71	27					0.22	0.039	0.1	0.02	1	0.379	37.9	0	0.054	32	43	25	0.433	0	0

V: taux de saturation en %.
S: somme des bases échangeables.
CEC: Capacité d'Echange Cationique.
CECE=S+(Al3+)+(H+).
m: indice Kamprath.
Sc: taux de saturation en cations acides.

VOLUME I

APPENDIX 3.1

ATTACHMENT 3

PIPELINE SOIL DESCRIPTIONS (FRENCH)

1 FRAGMENTS DE FORÊT

1.1 FRAGMENT N°01

Fosse 1W

Localisation : Coordonnée UTM

0232676

7906374

931 m

Topographie : Mi-versant à pente forte 41-47%, drainage moyen à mauvais (>102 cm).

Végétation: *Misa paradisana*, *Psedia akisiana*, *Dypsis masoalensis*, *Maesa manseolata*. Forêt secondaire presque primaire semi-fermée : 75% ; 8-23 cm de diamètre et 10-15 m de hauteur ; degré d'anthropisme moyen (layon)

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 1Mo, 1H1, 1H2

Risque d'érosion : formation de ravin et lavaka de faible profondeur sur pente raide

Description :

Litière peu épaisse plus ou moins décomposée

0-12 cm : horizon A brune forte 7,5YR5/6, grumeleux, continu à éclats à la base. Présence de moyennes racines à la base. Texture argilo-limoneuse. Cohésion moyenne. Friable à meuble.

12-49 cm : horizon B1 jaune rougeâtre 7,5YR6/8, argilo-sableux. Texture polyédrique à continue. Cohésion un peu forte. Enracinement faible. Transition progressive.

49 cm : horizon B2 sablo-limoneuse rouge 7,5YR5/8. Sans racine. Structure continue à polyédrique. Peu poreux. Cohésion moyenne à forte.

Fosse 1E

Localisation : Coordonnée UTM

0232790

7906337

960 m

Topographie : Sommet peu replat exposé d'Est à l'Ouest, drainage moyen à mauvais (>104 cm).

Végétation : Fragment de fragment forêt secondaire à structure ouverte discontinue presque primaire à transition avec savoka récent (2ans), *Misa paradisana*, *Anthocleista*, *Uapaca sp* (d=15-23 cm, h=8-14 m).

Type de sol : sol ferrallitique typique à structure polyédrique (oxisol)

Echantillons : 1EMo, 1EH1, 1EH2, 1EH3

Risque d'érosion : formation de ravin et lavaka de faible profondeur sur pente raide

Description :

Litière plus ou moins décomposée peu épaisse 0-7 cm, riche en feuille

0-18 cm : horizon A brun jaunâtre 7,5YR5/6, grumeleux, poreux, bien explorée par les racines (chevelues). Texture argilo-limoneuse. Cohésion moyenne friable et meuble. Transition progressive.

18-24 cm : horizon B1 brun 7,5YR5/2, polyédrique à continue, argilo-limoneux. Pores moyens. Cohésion faible, friable et concrétionnée (stone-line) à la base de moyenne taille (4-35 cm). Enracinement faible et dressé. Transition progressive.

24-41 cm : horizon B2 brun jaunâtre 7,5YR6/8, continue à tendance polyédrique, limono-argileux. Pores fines. Cohésion faible, friable. Enracinement faible. Transition progressive.

41 cm< : horizon BC rosâtre 7,5YR6/8, limoneux à structure continue. Peu de racine. Peu poreux. Cohésion moyenne.

Fosse 1NMV

Localisation : Coordonnée UTM

0232650

7906740

906 m

Topographie : Bas de versant à pente abrupt (52-63%), près de Mitimbato (ruisseaux vers le SE), mauvais drainage (>112 cm).

Végétation : Savoka environ 3 ans après Tavy, Espèces pionnières (Rubis nicolus, Dombeya, Psidium, Ravenala).

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 1NMVMO, 1NMVH1, 1NMVH2

Risque d'érosion : formation de ravin de faible profondeur sur pente raide

Description :

Litière plus ou moins bien décomposée et peu épaisse

0-17 cm : horizon A brun sombre 7,5YR5/6, grumeleuse, bien poreux, argilo-limoneuse. Bon enracinement. Cohésion moyenne. Friable et meuble.

17-53 cm : horizon B1 jaune rougeâtre 7,5YR6/8, polyédrique à continue, argilo-limoneux plus sableux à la base. Cohésion faible. Enracinement moyen. Transition progressive.

40-90 cm : horizon B2 sablo-limoneux, rouge 7,5YR5/8. Peu de racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 1NSO

Localisation : Coordonnée UTM

0232736

7906593

928 m

Topographie : Sommet aiguë à pente abrupte (57-63%), drainage moyen à mauvais (>101 cm)

Végétation : Forêt plus ou moins éclairée par les feux et les exploitations (année 1995) à 35% de recouvrement. *Uapaca*, *Molanga*, *Mammea madagascariensis*, *Harungana*, D=9-18 cm, h=6-12m. Degré d'anthropisme nul.

Type de sol : sol typique à structure polyédrique (oxisol)

Echantillons : 1NSoMO, 1NSOH1, 1NSoH2

Risque d'érosion : Petite formation de ravin et lavaka de faible profondeur sur pente raide

Description :

Litière bien décomposée et épaisse

0-47 cm : horizon A brun 7,5YR5/4, grumeleux, continue à éclats à la base. Bon enracinement. Texture argilo-limoneuse. Cohésion moyenne. transition progressive.

47-65 cm : horizon B1 jaune rougeâtre 7,5YR6/8, polyédrique à continu, limono-argileux. Cohésion faible. Enracinement moyen. Transition progressive.

65 cm <: horizon B2 limoneux. Peu de racine. Structure continue à éclats. Peu poreux. Cohésion moyenne.

Fosse 1MV

Localisation : Coordonnée UTM

02

79 m

Topographie : bas de pente abrupt (60%), près ruisseau et de marais, mal drainé.

Végétation : Savoka 5 ans, à *Psidium*, *Dombeya*, *Ravenala*

Type de sol : sol ferrallitique rajeuni (ultisol)

Echantillons : 1MVMO, 1MVH1, 1MVH2

Risque d'érosion : formation de ravin et lavaka peu profond

Description :

Litière mince

0-23 cm : horizon A rouge 2,5YR5/6, grumeleux à tendance continue et continue à éclats à la base. Bonne exploration des racines. Texture argilo-limoneuse. Cohésion faible.

23-47 cm : horizon B1 jaune rougeâtre 7,5YR6/8, polyédrique à continu, argilo-limoneuse. Pore fine. Cohésion un peu forte. Enracinement faible. Transition progressive.

47 cm < : horizon B2 limono-argileux. Peu de racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

1.2 FRAGMENT N°02

Fosse 2SO

Localisation : Coordonnée UTM
0233524
7907041
919 m

Topographie : Sommet aiguë à pente moyenne (33-46%), drainage moyen à mauvais (>96 m)

Végétation : Forêt d'*Eucalyptus* semi-ouvert (70%) âgée de 7 ans environ ;
d= 17-36 cm, h=11-20 m.

Type de sol : sol typique à structure polyédrique (oxisol)

Echantillons : 2SOMo, 2SoH1, 2SoH2

Risque d'érosion : formation de ravin et de rigole de faible profondeur sur pente raide

Description :

Litière plus ou moins décomposée peu épaisse

0-13 cm : horizon A brun jaunâtre 10YR5/8, grumeleux. Très bon enracinement. Texture sablo-limoneuse. Cohésion moyenne. Transition progressive.

13-34 cm : horizon AB jaune 10YR7/8, grumeleux, argilo-limoneux. Cohésion faible. Enracinement moyen. Transition progressive.

34-57 cm : horizon B1 rouge vive 7,5YR3/8, limono-argileux. Peu de racine. Structure polyédrique à continue à éclats. Peu poreux. Cohésion moyenne.

57 cm< : horizon BC rouge clair, limono-sableux, structure continue. Peu poreux. Présence des concrétions (stone-lines) 4-8 cm environ de diamètre. Cohésion moyenne.

Fosse 2EMV

Localisation : Coordonnée UTM
0233520
7906885
862 m

Topographie : versant de pente abrupte (52%), drainage moyen (>100 cm)

Végétation : Forêt d'*Eucalyptus* 4 à 5 ans environ, structure ouverte (45%),
d=7-13 cm ; h=6-14 m

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 2EMVMO, 2EMVH1, 2EMVH2

Risque d'érosion : formation de ravin de moyenne profondeur sur pente raide et surface ouverte.

Description :

Litière plus riche en feuille, plus ou moins décomposée et peu épaisse

0-27 cm : horizon A brun 7,5YR5/4, grumeleux, limono-sableux, très poreux. Présence de grains de quartz et de granite. Enracinement moyen. Cohésion moyenne. Transition progressive.

27-57 cm : horizon B1 jaune rougeâtre 7,5YR6/8, polyédrique, poreux et avec concrétions de basalte (2-4 mm), texture limono-sableux. Cohésion moyenne. Enracinement faible. Transition progressive.

57 cm< : horizon B2 limoneux, rouge 2,5YR6/8, Peu de racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 2NMV

Localisation : Coordonnée UTM

0233484

7907108

894 m

Topographie : mi-versant à pente forte 47-52% exposé de NE et NW, drainage moyen (>100 cm)

Végétation : Savoka à espèces pionnières (*Rubis nicolus*, *Dombeya*,) et arborée d'Eucalyptus de 1 à 2 ans de d=4-11 cm, h=4-8 m

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 2NMVMo, 2NMVH1, 2NMVH2, 2NMVH3

Risque d'érosion : formation de ravin, rigole et lavaka de faible profondeur sur pente latérale

Description :

Litière plus ou moins décomposée et peu épaisse

0-23 cm : horizon A jaune rougeâtre 10YR5/8, grumeleux, Limono-sableux. Présence des concrétions et de stone-lines de quartz 3mm. Cohésion moyenne. Enracinement bon. Très poreux. Transition progressive.

23-60 cm : horizon B1 jaune 10YR7/8, polyédrique, limono-sableux. Cohésion moyenne et friable. Enracinement moyen. Pores moyens. Transition progressive.

60-111 cm : horizon B2 limoneux, de couleur rouge jaunâtre claire 10YR6/4. Peu de racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

111 cm< : horizon BC argilo-limoneux, rosâtre, continue à polyédrique, peu poreux. Cohésion moyenne à forte.

Fosse 2SSO

Localisation : Coordonnée UTM

0233443

7906615

924 m

Topographie : Sommet plus ou moins aiguë, drainage moyen à mauvais (>100 cm)

Végétation : Fragment de forêt secondaire presque primaire à *Coffea*, *Syzygium*, *Ocotea* ; Structure ouverte (45%) ; d=13-22 cm ; h=9-17 m.

Type de sol : sol typique à structure polyédrique (oxisol)

Echantillons : 2SsoMo, 2SSOH1, 2SSOH2

Risque d'érosion : formation d'érosion en nappe de faible profondeur.

Description :

Litière bien décomposée et plus épaisse

0-41 cm : horizon A brun sombre 7,5YR5/6, grumeleux. Bon enracinement. Texture argilo-limoneuse. Poreux. Cohésion moyenne . Présence des concrétions et stone-line à la base de l'horizon (pisolite de taille environ 4 à 35mm)

41-67 cm : horizon B1 jaune brun 7,5YR6/8, Polyédrique à continu, argilo-limoneux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

67 cm< : horizon B2 limoneux, rouge 7,5R5/8. Peu de racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 2SMV

Localisation : Coordonnée UTM

0233443

7906546

897 m

Topographie : Mi-versant à pente abrupte 47-61%, exposé SW et NE

Végétation : Forêt secondaire plus ou moins fermée (85%), à *Anthocleista*, *Harungana*, *Uapaca*, *Ocotea* et *Fougère* ; d=12-27 cm ; h=11-17m, sous-bois plus ou moins évolué et régénération très poussées.

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 2SMVMO, 2SMVH1, 2SMVH2

Risque d'érosion : formation de ravin et lavaka de faible profondeur sur pente raide

Description :

Litière bien décomposée plus épaisse

0-32 cm : horizon A brun sombre à claire 7,5YR4/6, grumeleux, très poreux. Bon enracinement, bien exploré par les racines. Texture limono-sableux. Cohésion moyenne .

32-72 cm : horizon B1 jaune brun 7,5YR6/8, polyédrique, sablo-limoneux. Cohésion un peu forte et friable. Enracinement faible. Transition progressive.

40 cm< : horizon B2 rouge 2,5YR4/6, limono-sableux avec des grains de quartz (1-3 mm). Peu de racine. Structure polyédrique à continue. Peu poreux. Cohésion moyenne.

1.3 FRAGMENT N°03

Fosse 3N

Localisation : Coordonnée UTM
0233598
7906497
908 m

Topographie : Sommet aiguë et ligne de crête suivant SW et NE, bien drainé (>96 cm)

Végétation : Forêt secondaire presque primaire à structure fermée, dominée par *Wenmenia*, *Anthocleista*, *Ravensara*, et peu d'*Eucalyptus*. D= 17-33 cm ; h=7-19m.

Type de sol : sol typique à structure polyédrique (oxisols)

Echantillons : 3NSOMO, 3NSOH1, 3NSOH2

Risque d'érosion : formation d'érosion en nappe.

Description :

Litière bien décomposée riche plutôt de tiges que de feuilles et plus épaisse

0-35 cm : horizon A brun sombre 7,5YR4/2, grumeleux, à éclats à la base. Bien exploré par les racines. Texture sablo-limoneux. Cohésion moyenne. Transition progressive.

35-54 cm : horizon B1 jaune brun 7,5YR6/8, Polyédrique, sablo-limoneuse. Cohésion un peu forte. Enracinement moyen. Présence de concrétions à la base (quartzeux de 1-3 mm). Transition progressive.

54 cm<: horizon B2 limoneux, rouge 2,5YR5/8. Enracinement moyen. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 3MV

Localisation : Coordonnée UTM
0233639
7906369
902 m

Topographie : Mi-versant à pente abrupte (57%), bien drainé (>85 cm)

Végétation : Forêt secondaire de transition à savoka à structure fermée (55%), *Mammea madagascariensis*, *Anthocleista*, *Ravensara*, *Dombeya*, *Rubis nicolus* ; d=11-27 cm ; h=7-14 m

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 3NMVMO, 3NMVH1, 3NMVH2

Risque d'érosion : formation de ravin et lavaka de faible profondeur

Description :

Litière bien décomposée moyennement épaisse

0-42 cm : horizon A brun sombre 7,5YR4/2, grumeleux. Enracinement bon. Présence de concrétions moyennes à la base (grains de quartz). Texture sablo-limoneuse. Cohésion moyenne.

42-57 cm : horizon B1 jaune brun 7,5YR6/8, Polyédrique, Texture sablo-limoneuse. Cohésion un peu forte. Enracinement moyen. Transition progressive.

57 cm < : horizon B2 limoneux. peu racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 3EMV

Localisation : Coordonnée UTM

0233632

7906113

880 m

Topographie : bas de pente abrupt (42-47%), bien drainé

Végétation : Forêt d'*Eucalyptus* (sous taillis) environ 8 ans, structure plus ou moins ouverte 65%, d=12-17 cm, h=9-16 m

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 3EMVMO, 3EMVH1, 3EMVH2, 3EMVH3

Risque d'érosion : formation de ravin et rigole voire lavaka de faible profondeur sur pente raide

Description :

Litière plus ou moins décomposée moyennement épaisse

0-7 cm : horizon A1 brun sombre 7,5YR4/6, grumeleux, friable et meuble. Bon enracinement. Très poreux. Texture limono-sableuse.

7-31 cm : horizon A2 brun rosâtre (pinkish gray) 7,5YR6/2, grumeleux, limono-sableux. Cohésion moyenne. Enracinement bon. Très poreux. Transition progressive.

31-45 cm : horizon B1 limoneux. Rouge claire 7,5YR6/8. Peu de racine. Structure polyédrique à continue. Moyennement poreux. Cohésion moyenne à forte.

45 cm < : horizon B2 limoneux, rouge vive . Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 3SO Centre

Localisation : Coordonnée UTM

0233508

7906094

901 m

Topographie : Sommet plus ou moins aiguë, ligne de crête suivant Sud. Bien drainé.

Végétation : Forêt d'*Eucalyptus* environ 8 ans régénération, d=11-19 cm, h=9-16 m, semi-fermée 50%, Sous bois dominés par les espèces pionnières (Comme Chez Savoka récente)

Type de sol : sol ferrallitique typique à structure polyédrique (oxisols)

Echantillons : 3SOMO, 3SOH1, 3SOH2

Description :

Litière bien décomposée et épaisse

0-64 cm : horizon A épais brun sombre 7,5YR4/4, grumeleux, Texture sablo-limoneuse. Bonne pénétration des racines. Très poreux. Cohésion moyenne.

64-67 cm : horizon B1 peu épais rouge 2,5YR4/8, Structure polyédrique bien développée, Texture sablo-limoneuse. Cohésion un peu forte. Enracinement moyen. Transition progressive.

67 cm < : horizon B2 rouge 7,5R4/8, sablo-limoneux concrétionnés avec des grains de quartz et de pisolite (4-12mm). Peu de racine. Structure polyédrique à continue. Moyennement poreux. Cohésion moyenne.

Fosse 3MV

Localisation : Coordonnée UTM

0233310

7905567

886 m

Topographie : Mi-versant à pente concave plus ou rectiligne 39-45%

Végétation : Forêt naturelle secondaire de transition en forêt d'*Eucalyptus* plus ou moins fermée (45%), à *Mammea madagascariensis*, *Ravensara*, *Anthocleista* ; d=11-18 cm ; h11-17 m.

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 3MVMO, 3MVH1, 3MVH2

Risque d'érosion : formation de ravins de faible profondeur

Description :

Litière moyennement décomposée et moins épaisse

0-52 cm : horizon A épais brun jaunâtre 10YR5/8, grumeleux. Texture Limono-sableuse. Bonne pénétration des racines. Très poreux. Cohésion moyenne. Transition progressive.

52-87 cm : horizon B1 jaune brunâtre 10R5/8, polyédrique, Limono-sableux. Cohésion un peu forte. Enracinement moyen. Pores moyens. Présence des stone-lines (pisolite de taille variant de 4-12 cm) Transition progressive.

87 cm < : horizon B2 argilo-sableux, rouge claire 10R5/8. Peu de racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

1.4 FRAGMENT N°04

Fosse 4

Localisation : Coordonnée UTM
0234290
7907081
930 m

Topographie : Versant à pente concave bien marquée 47-89 % exposée au NW suivant la ligne de crête, bien drainé.

Végétation : Forêt d'*Eucalyptus* environ 8 ans plus ou moins ouvert 25%, d=11-26 cm, h=8-16 m

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 4MO, 4H1, 4H2

Risque d'érosion : formation de ravin et lavaka de faible profondeur sur pente raide

Description :

Litière mince peu développée

0-24 cm : horizon A brun clair 7,5YR5/6, grumeleux, très poreux et bonne pénétration des racines. Texture limono-sableuse. Cohésion moyenne.

24-48 cm : horizon B1 jaune brun 7,5YR6/8, structure polyédrique plus ou moins bien développée, texture limono-sableux. Pores moyens. Cohésion un peu forte. Enracinement moyen (seuls les grosses racines). Transition progressive.

48 cm < : horizon B2 sablo-limoneux, rouge claire 2,5YR6/8, racine. Structure continue à éclats à tendance polyédrique. Peu poreux. Cohésion moyenne à forte.

Fosse 4 EMV

Localisation : Coordonnée UTM
0234437
7907002
946 m

Topographie : Mi-versant à pente concave 27 à 34%, bien drainé (>70 cm), suivant ligne de crête NW vers SE.

Végétation : Forêt secondaire à structure primaire plus ou moins fermée (25%), dominée par *Anthocleista Harungana*, *Eucalyptus* ; d=6-18 cm ; h=6-16 m

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 4EMVMO, 4EMVH1, 4EMVH2

Risque d'érosion : formation de ravin et de rigole

Description :

Litière bien décomposée moins épaisse

0-29 cm : horizon A brun clair 7,5YR5/6, grumeleux, très poreux. Texture limono-sableuse. Cohésion moyenne. Bon enracinement. Transition progressive.

29-53 cm : horizon B1 jaune brun 7,5YR6/8, Polyédrique peu développée, limono-sableux. Moyennement poreux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

53 cm< : horizon B2 sablo-limoneux, rouge clair 2,5YR6/8. Peu à pas de racine. Structure continue à éclats. Peu poreux. Cohésion moyenne.

Fosse 4SO centre

Localisation : Coordonnée UTM

0234248

7906887

927 m

Topographie : sommet plus ou moins aiguë

Végétation : Forêt naturelle de transition secondaire à Eucalyptus seuls, structure ouverte 35%, dominée par *Anthocleista*, *Mammea madagascariensis*, *Wenmenia*, *Harungana* ; d=7-13 cm ; h=9-17 m

Type de sol : sol typique à structure polyédrique (oxisols)

Echantillons : 4SoMO, 4SoH1, 4SOH2

Risque d'érosion : formation de ravin et érosion en nappe

Description :

Litière plus ou moins mince très bien décomposée

0-23 cm : horizon A brun jaunâtre 10YR5/8, grumeleux, continue à éclats à la base. Présence de moyennes racines horizontales à la base. Texture limono-sableuse. Cohésion moyenne. Très poreux. Transition progressive.

23-60 cm : horizon B1 jaune 10YR7/8, polyédrique bien développée, limono-sableux. Cohésion un peu forte. Enracinement moyen. Présence de grains de quartz et de Granite de taille réduite (3-5 mm) à la base. Transition progressive.

60 cm< : horizon B2 limoneux brun clair à jaunâtre. Sans à peu de racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 4WMV

Localisation : Coordonnée UTM

0234129

7906959

861 m

Topographie : bas de pente abrupt (65%), près ruisseau

Végétation : Savoka 3ans, à *Fougère*, *Hypparhenia*, *Psidium* et avec un certain nombre d'Eucalyptus dispersés (d=4-12 cm ; h=4-7m)

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 4WMVMo, 4WMVH1, 4WMVH2

Risque d'érosion : formation de ravin et lavaka de faible profondeur

Description :

Litière bien développée et plus épaisse (0-9 cm)

0-54 cm : horizon A épais, brun clair 7,5YR4/6, grumeleux, continue à éclats à la base. Très bon enracinement. Bien poreux. Texture limono-sableuse. Cohésion moyenne. Transition progressive.

54-79 cm : horizon B1 brun rosâtre 7,5YR7/4, Polyédrique peu développé, limono-sableux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

79 cm< : horizon B2 limono-argileux, rouge vive 2,5YR4/8. Peu de racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 4SO

Localisation : Coordonnée UTM

0234326

7907052

954 m

Topographie : Sommet pointu, bien drainé

Végétation : Forêt naturelle presque primaire à *Faucherea*, *Fougère*, *Psidium*, *Macaranga*, d=3-13 cm, h=10-12 m, structure semi-fermée 35%.

Type de sol : sol typique à structure polyédrique (oxisol)

Echantillons : 4SoMo, 4SOH1, 4SOH2

Risque d'érosion : formation de ravin et érosion en nappe

Description :

Litière moyennement épaisse et plus ou moins décomposée

0-34 cm : horizon A rouge clair (Weak red) 7,5YR5/2, grumeleux, continue à éclats à la base. Bonne pénétration des racines. Texture argilo-sableuse. Porosité moyenne. Cohésion moyenne. Transition progressive.

34-51 cm : horizon B1 brun clair 7,5YR4/6, Structure polyédrique plus ou moins développée, Sablo-limoneux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

51 cm< : horizon B2 limono-sableux, brun jaunâtre 7,5YR6/8. Peu de racine. Structure continue à éclats à tendance polyédrique à la base. Peu poreux. Cohésion moyenne à forte.

1.5 FRAGMENT N°05

Fosse 5SO

Localisation : Coordonnée UTM

0234480

7907383

898 m

Topographie : sommet concave pointu à pente 15-23%, bien drainé, exposée au SW et au NE

Végétation : régénération d'*Eucalyptus* 7 ans, semi-ouvert (35%), d=11-17 cm, h=9-17 m.

Type de sol : sol typique à structure polyédrique (oxisol)

Echantillons : 5SoMO, 5SOH1, 5SOH2, 5SOH3

Risque d'érosion : formation de ravin et érosion en nappe

Description :

Litière bien décomposée et épaisse

0-11 cm : horizon A brun jaunâtre 10YR5/8, grumeleux. Présence de moyennes racines horizontales à la base. Texture sablo-limoneuse. Cohésion moyenne. Transition brusque.

11-34 cm : horizon B1 jaune 10YR7/8, polyédrique, argilo-limoneux. Cohésion un peu forte. Enracinement moyen. Moyennement poreux. Présence des concrétions de quartz (2-4mm). Transition progressive.

34-53 cm : horizon B2 limono-argileux, jaune 10YR8/8, structure polyédrique à tendance continue et structure continue à éclats à la base. Peu de racine. Peu poreux. Cohésion moyenne à forte.

53 cm< : horizon BC rouge clair 10R6/8, limono-sableux, Structure continue à éclats. Peu poreux. Cohésion moyenne.

Fosse 5BV

Localisation : Coordonnée UTM

0234395

7907413

856 m

Topographie : Bas de pente abrupt (33-39%) concave exposée au NW, drainage moyen à bien.

Végétation : Forêt à *Eucalyptus* environ 3 ans (d=9-13 cm, h=7-14 m) associée à *Savoka* à *Radriaka*, *Clidemia*. Structure plus ou moins dispersée. Présence de Tavy.

Type de sol : sol typique à structure polyédrique (oxisol)

Echantillons : 5BVMO, 5BVH1, 5BVH2

Risque d'érosion : formation de ravin et lavaka de faible profondeur sur pente raide

Description :

Litière plus ou moins décomposée et moins épaisse

0-51 cm : horizon A brun clair 7,5YR4/6, grumeleux. Présence de moyennes racines horizontales à la base. Texture limono-sableuse. Cohésion moyenne .

51-72 cm : horizon B1 jaune brun 7,5YR6/2 (pinkish gray), Polyedrique bien développée, limono-sableux. Présence des concrétions de pisolite (2mm). Cohésion un peu forte. Enracinement moyenne. Transition progressive.

72 cm< : horizon B2 limono-argileux avec des grains de quartz, rouge clair 2,5YR6/8. Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 5MV

Localisation : Coordonnée UTM

0234560

7907729

863 m

Topographie : versant de pente moyenne (31-42%), concave et exposée au SE

Végétation : forêt naturelle secondaire à *Anthocleista* et *Mamme madagascariensis* associée avec de forêt d'*Eucalyptus* et savoka récente, d=8-14 cm, h=8-16 m, Structure variée et peu de Tavy.

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 5MVMO, 5MVH1, 5MVH2, 5MVH3

Description :

Litière bien décomposée et moins épaisse (0-5 cm)

0-17 cm : horizon A peu épais brun jaunâtre 10YR5/8, grumeleux, continue à éclats à la base. Bon enracinement. Texture limono-sableuse. Très poreux. Cohésion moyenne.

17-38 cm : horizon B1 jaune 10YR7/8, polyedrique bien développée, moyennement poreux, sablo-limoneux. Cohésion moyenne. Enracinement moyen. Transition progressive.

38-59 cm : horizon B2 argilo-limoneux avec des grains de quartz à la base. Peu ou pas de racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

59 cm< : horizon BC limoneux, rouge clair 10R6/8, continue, peu poreux. Cohésion moyenne à forte.

1.6 FRAGMENT N°06

Fosse 6MV

Localisation : Coordonnée UTM

0234629

7907346

712 m

Topographie : Versant à pente moyenne comprise entre 23 à 31%, concave, exposée à l'Est.

Végétation : Savoka ancienne d'*Eucalyptus* et des espèces pionnières à structure ouverte 25%, d=7-12 cm, h=6-14 m.

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 6MVMo, 6MVH1, 6MVH2

Risque d'érosion : formation de ravin et lavaka de faible profondeur

Description :

Litière bien décomposée et peu épaisse

0-22 cm : horizon A brun sombre 7,5YR3/4, grumeleux, Très poreux. Enracinement bon. Texture limono-sableux. Cohésion moyenne. Transition progressive.

22-47 cm : horizon B1 brun 7,5YR5/4, polyédrique peu développée, limono-argileuse. Cohésion moyenne. Enracinement moyen. Transition progressive.

47 cm : horizon B2 sablo-limoneux, brun sombre à clair 7,5YR5/8. Sans racine. Structure à tendance continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 6SO

Localisation : Coordonnée UTM

0234897

7907324

812 m

Topographie : Sommet pointu à pente 43-62%, concave plus ou moins rectiligne, bien drainé.

Végétation : Forêt de transition naturelle à *Eucalyptus* avec peu des espèces pionnières, dominée par *Hazoporetika*, *Harungana*, *Psidium*, d=6-12 cm, h=4-10 m, structure semi-fermée (35%).

Type de sol : sol typique à structure polyédrique (oxisol)

Echantillons : 6SoMo, 6SOH1, 6SOH2

Risque d'érosion : formation de ravin et érosion en nappe

Description :

Litière plus ou moins décomposée riche en feuille et peu épaisse

0-37 cm : horizon A brun clair 7,5YR4/6, grumeleux, à éclats à la base. Présence de moyennes racines plus ou moins horizontales à la base. Texture limono-sableuse. Présence de concrétions à la base (pisolite). Cohésion moyenne.

37-49 cm : horizon B1 jaune brun 7,5YR6/2 (Pinkish gray), polyédrique peu développée, limoneux. Meuble et friable. Enracinement moyen. Transition progressive.

49 cm< : horizon B2 limoneux, rouge clair 2,5YR6/8. Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

1.7 FRAGMENT N°07

Fosse 7

Localisation : Coordonnée UTM
0234818
7907623
856 m

Topographie : bas fonds de vallée encaissée peu large, mal drainé (toujours inondé)

Végétation : Marais à Cyperaceae

Type de sol : sol hydromorphe organique (histosols)

Echantillons : 7BFMO, 7BFH1, 7BFH2

Risque d'érosion : Erosion en nappe

Description :

Litière très épaisse peu décomposée et riche en matière fraîche à la base

0-60 cm : horizon A brun 7,5YR5/4, grumeleux, continue à éclats à la base. Collante et émoussée. Peu poreux. Texture limono-sableux. Cohésion faible.

60-73 cm : horizon B1 jaune brun 7,5YR7/6, polyédrique à continue, limono-sableux. Cohésion faible. Enracinement moyenne. Présence des éléments minéraux comme Mica particulière. Transition progressive.

73 cm < : horizon B2 sableux micacé et de couleur rose claire (pinkish white) 7,5YR8/2. Sans racine. Structure continue à éclats. Peu poreux. Cohésion faible.

Fosse 7SMV

Localisation : Coordonnée UTM
0234599
7907889
812 m

Topographie : bas de pente abrupt (47-67%), concave exposée à l'est et au sud

Végétation : Forêt à *Faucherea*, *Mammea madagascariensis*, *Canthium*, structure bien fermée (65%), d=13-17 cm, h=14-22 m.

Type de sol : Sol ferrallitique rajeuni (ultisol)

Echantillons : 7SMO, 7SH1, 7SH2

Risque d'érosion : faible (formation de ravin et lavaka de faible profondeur)

Description :

Litière plus décomposée et moyennement épaisse

0-27 cm : horizon A brun gris 7,5YR6/2 (Pinkish gray), grumeleux, continue à éclats à la base. Très bon enracinement. Texture limono-argileuse. Porosité moyenne. Cohésion faible .

27-36 cm : horizon B1 jaune brun 7,5YR7/6, polyédrique, limono-argileux. Cohésion moyenne. Enracinement moyen. Transition progressive.

36 cm < : horizon B2 limono-sableux, rouge clair 2,5YR6/8. Peu à pas racine. Structure continue à éclats. Peu poreux. Cohésion faible à moyenne.

Fosse 7MV

Localisation : Coordonnée UTM

0234875

7907681

913 m

Topographie : pente légèrement abrupte 23-37% exposée au Nord

Végétation : Forêt secondaire à *Faucherea*, *Mammea madagascariensis*, *Canthium*, structure très fermée (74%), d=16-34 cm, h=12-19m.

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 7MVMo, 7MVH1, 7MVH2

Risque d'érosion : formation de ravin et rigole de faible profondeur sur pente la plus raide

Description :

Litière plus ou moins décomposée et peu épaisse

0-34 cm : horizon A brun gris 7,5YR6/2, grumeleux, continue à éclats à la base. Bon enracinement. Très poreux. Texture limono-argileuse. Cohésion faible.

34-61 cm : horizon B1 jaune brun 7,5YR7/6, polyédrique à continu, limono-argileux. Cohésion moyenne. Enracinement moyen. Transition progressive.

61 cm : horizon B2 limono-sableux, rouge clair 2,5YR6/8. Peu de racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à faible.

Fosse 7EMV

Localisation : Coordonnée UTM

0235012

7907681

845 m

Topographie : Versant à pente 19-31% concave exposée au sud, bien drainé.

Végétation : Forêt d'*Eucalyptus* semi-ouvert (35%) environ 6 ans, d=11-17 cm, h=9-12 m

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 7EMVMo, 7EMVH1, 7EMVH2

Description :

Litière peu épaisse bien décomposée et riche en matière fraîche à la base

0-15 cm : horizon A brun jaunâtre 10YR5/8, grumeleux, friable et meuble. Bonne pénétration de racines. Très poreux. Texture sablo-limoneux. Cohésion moyenne. Transition progressive.

15-39 cm : horizon B1 jaune 10YR7/8, polyédrique, argilo-limoneux. Cohésion un peu forte. Enracinement moyen. Moyennement poreux. Transition progressive.

39 cm< : horizon B2 limoneux avec des grains de quartz (2-3 mm). Sans racine. Structure continue à éclats. Peu poreux. Cohésion faible.

Fosse 7N

Localisation : Coordonnée UTM

0234669

7907685

879 m

Topographie pente abrupte (47-69%), concave plus ou moins rectiligne suivant la ligne de crête.

Végétation : Savoka environ 2 à 3 ans à *Dombeya*, *Rubis nicolus*.

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 7NMVMO, 7NMVH1, 7NMVH2

Description :

Litière plus ou moins décomposée et d'épaisseur moyenne.

0-17 cm : horizon A brun sombre 7,5YR5/6 à tendance jaunâtre à la base, grumeleux, continue à éclats à la base. Très poreux. Texture argilo-limoneuse. Enracinement moyen. Cohésion moyenne. Transition progressive.

17-57 cm : horizon B1 jaune brun 7,5YR6/8, polyédrique peu développée, argilo-limoneux. Cohésion un peu forte. Peu poreux. Enracinement faible. Transition brusque.

57 cm< : horizon B2 sablo-limoneux, rouge 7,5YR5/8. Sans racine. Structure polyédrique à tendance continue (à éclats à la base). Peu poreux. Cohésion moyenne à forte.

1.8 FRAGMENT N°08

Fosse 8E

Localisation : Coordonnée UTM
0235287
7907305
950 m

Topographie : Pente convexe 33-51%, bien drainé

Végétation : Forêt secondaire à *Ocotea* (30%) : d=11-27 cm, h=9-16 m ; à *Canthium* : 9-12 cm, h=4-6 m, et à *Syzygium*la, *Mammea madagascariensis*, Structure bien fermée.

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 8EMVMO, 8EMVH1, 8EMVH2

Risque d'érosion : formation de ravin et lavaka de faible profondeur sur pente raide

Description :

Litière épaisse bien décomposée (Matière sèche : feuilles de *Ocotea*)

0-21 cm : horizon A brun sombre 7,5YR3/4, grumeleux, très poreux. Bonne exploration des grosses racines et riche en chevelures. Texture limono-argileuse. Cohésion faible. Transition progressive à tendance brusque.

21-47 cm : horizon B1 brun 7,5YR5/4, polyédrique à continu, limono-argileux. Cohésion moyenne. Pores moyens. Enracinement moyen. Transition progressive.

47 cm< : horizon B2 Sablo-limoneux, brun sombre 7,5YR5/8. Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 8N

Localisation : Coordonnée UTM
0235097
7907388
911 m

Topographie : versant de pente légèrement abrupte (34-39%), convexe exposée au NE, bien drainé à moyen, près ruisseau.

Végétation : Forêt d'*Eucalyptus* semi-ouverte (30%), environ 5-6ans, à Ravensara et Phragmites, d=10-16 cm, h=8-13 m.

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 8NMO, 8NH1, 8NH2

Description :

Litière riche en matière fraîche plus ou moins décomposée

0-17 cm : horizon A brun jaunâtre 10YR5/8, grumeleux, continue à éclats à la base. Présence de moyennes racines à la base. Texture sablo-limoneuse. Cohésion moyenne. Transition progressive.

17-41 cm : horizon B1 jaune 10YR7/8, polyédrique à tendance continue, argilo-argileux. Cohésion un peu forte. Enracinement moyen (tubulures). Transition progressive.

41 cm< : horizon B2 limoneux. Rouge Clair 10R6/8. Présence seules les grosses racines. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 8SO

Localisation : Coordonnée UTM

0235191

7907297

998 m

Topographie : Sommet aiguë à pente raide 39-56%, concave exposée au N, présence de source d'eaux. Drainage moyen.

Végétation : Forêt secondaire presque primaire à *Faucherea*, *Mammea madagascariensis*, *Canthium*, *Wenmenia*, d=12-18 cm, h=12-17 m, Structure moyennement fermée 55%.

Type de sol : sol typique à structure polyédrique (oxisol)

Echantillons : 8SoMO, 8SOH1, 8SOH2

Risque d'érosion : formation de ravin et érosion en nappe

Description :

Litière bien décomposée.

0-33 cm : horizon A gris brun 7,5YR6/2 (Pinkish gray), grumeleux, continue à éclats à la base. Pores moyens à fins. Très bonne pénétration des racines. Texture limono-argileuse. Cohésion moyenne .

33-47 cm : horizon B1 jaune brun 7,5YR7/6, polyédrique à continu, limono-argileux. Cohésion un peu forte. Enracinement moyen. Peu poreux. Transition progressive.

47 cm< : horizon B2 limono-sableux, rouge clair 2,5YR6/8. Grosses racines. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 8W

Localisation : Coordonnée UTM

0235024

7907009

919 m

Topographie : pente concave 31-37%, près ruisseau, Moyennement drainé.

Végétation : Forêt à structure fermée (55%), dominée par *Mammea madagascariensis*, *Syzygiumla*, *Wenmenia*, *Canthium*, *Bamboo*. D=6-22 cm, h=7-12 m.

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 8WMO, 8WH1, 8WH2

Description :

Litière épaisse bien décomposée

0-34 cm : horizon A brun 10YR5/3, grumeleux, continue à éclats à la base. Présence de moyennes racines horizontales à la base. Texture limono-argileuse. Cohésion moyenne. Très poreux. Transition à tendance brusque.

34-43 cm : horizon B1 jaune 10YR7/8, polyédrique à continu, limono-sableux. Pores moyens. Cohésion un peu forte. Enracinement moyen. Transition progressive.

43 cm< : horizon B2 brun jaunâtre 10YR6/8, limoneux avec des grains de quartz. Grosses racines. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

1.9 FRAGMENT N°09

Fosse 9SO

Localisation : Coordonnée UTM
0235180
7907798
870 m

Topographie : Sommet plus ou moins pointu. Bien drainé.

Végétation : Forêt à structure plus fermée, dominée par *Canthium*, *Wenmenia*, *Erythroxylum*, d=8-38 cm, h=8-15 m. Avec un certain nombre de régénération des espèces dominantes.

Type de sol : sol typique à structure polyédrique (oxisol)

Echantillons : 9SOMO, 9SOH1, 9SOH2

Risque d'érosion : formation de ravin et érosion en nappe.

Description :

Litière épaisse bien décomposée.

0-31 cm : horizon A gris brun 7,5YR6/2, jaunâtre à la base, grumeleux, très poreux. Bon enracinement. Texture limono-argileuse. Cohésion moyenne. Transition progressive.

31-43 cm : horizon B1 jaune brun 7,5YR7/6, polyédrique à continu, limono-argileux. Peu poreux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

43 cm : horizon B2 limono-sableux, rouge clair 2,5YR6/8. Peu de grosse racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 9MV

Localisation : Coordonnée UTM
0235118
7907744
867 m

Topographie : pente moyenne 31%, exposée au NE et bien drainé.

Végétation : Forêt secondaire à structure fermée dominée par *Ocotea* et *Faucherea*, d=27-34 cm, h=12-23 m.

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 9MVMO, 9MVH1, 9MVH2

Description :

Litière épaisse riche en matière fraîche non décomposée à la base

0-35 cm : horizon A brun 10YR5/3, grumeleux, continue à éclats à la base. Très poreux. Bon enracinement et bien développé. Texture limono-argileuse. Cohésion moyenne. Transition progressive.

35-47 cm : horizon B1 jaune 10YR7/8, polyédrique peu développée, limono-sableux. Pores moyens. Cohésion moyenne. Enracinement moyen. Transition progressive.

47 cm< : horizon B2 limoneux, brun jaune 10YR6/8. Moyennes racines. Structure continue à éclats. Peu poreux. Cohésion moyenne à faible.

Fosse 9N

Localisation : Coordonnée UTM

0235606

7908098

Topographie : Pente latérale abrupte 27—35% exposée SW et NE, bien à moyen drainé.

Végétation : Forêt secondaire à structure presque primaire bien fermée. D=19-31 cm, h=12-19 m.

Type de sol : sol jaune brun sur rouge jaunâtre à tendance peu évolué (ultisol)

Echantillons : 9NMO, 9NH1, 9NH2

Risque d'érosion : formation de ravin et lavaka de faible profondeur sur pente raide

Description :

Litière bien décomposée et plus ou moins peu développée à la base (matière fraîche).

0-25 cm : horizon A brun sombre 7,5YR4/6, grumeleux, continue à éclats à la base. Présence de moyenne taille de résidus de Ver de terre à la base. Texture sablo-limoneuse. Cohésion moyenne.

25-51 cm : horizon A2 jaune rouge 5YR5/6, polyédrique à continu, limono-sableux. Cohésion un peu forte. Enracinement moyen presque dressé horizontalement à la base. Transition progressive.

51-76 cm : horizon B1 limoneux, rouge 2,5YR6/8 avec des grains de quartz et pisolite. Grosse racine dressée horizontalement. Présence des concrétions. Peu poreux. Cohésion moyenne à forte.

76 cm< : horizon B2 limono-argileux, rouge clair 10YR6/8, peu poreux, Sans racine. Structure continue plus ou moins émoussée. Cohésion moyenne à faible.

Fosse 9E

Localisation : Coordonnée UTM

0235811

7907863

905 m

Topographie : versant à pente 31-42%, convexe exposée au NE, bien drainé. Près de ruisseaux.

Végétation : Forêt de transition d'*Eucalyptus* semi-ouverte 4 ans (d=9-14 cm ; h=11-17 m) à forêt naturelle à *Mammea madagascariensis*, *Canthium*, et à *Ocotea* (d=10-16 cm, h=8-12 m).

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 9EMO, 9EH1, 9EH2

Description :

Litière bien décomposée et peu épaisse (0-3 cm)

0-27 cm : horizon A brun jaunâtre 10YR5/8, grumeleux, Très poreux. Bon enracinement. Texture sablo-limoneuse. Cohésion moyenne.

27-47 cm : horizon B1 jaune 10YR7/8, polyédrique à continu, argilo-limoneux. Cohésion faible. Enracinement moyen. Peu poreux. Transition progressive.

47 cm< : horizon B2 Limoneux, rouge clair 10 R6/8. Peu de racine. Structure continue . Peu poreux. Cohésion moyenne à forte.

Fosse 9S

Localisation : Coordonnée UTM

0235891

7907682

896 m

Topographie : pente abrupte 41-53% concave, bien à moyen drainé, près ruisseau

Végétation : Forêt secondaire à structure presque primaire bien fermée (55%), dominée par *Wenmenia*, *Canthium*, *Syzygiumla*, et *Bamboo* ; d=7-19 cm, h=8-11 m.

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 9SMO, 9SH1, 9SH2

Risque d'érosion : formation de ravin et lavaka de faible profondeur sur pente raide

Description :

Litière plus ou moins décomposée et peu épaisse (0-6 cm)

0-38 cm : horizon A brun 10YR5/3, grumeleux, continue à éclats à la base. Pores moyens. Texture limono-argileuse. Enracinement bon. Cohésion moyenne. Transition progressive.

38-41 cm : horizon B1 jaune 10YR7/8, polyédrique à continu, limono-sableux. Présence de moyennes racines horizontales à la base. Cohésion un peu forte. Enracinement moyen. Transition progressive.

41 cm< : horizon B2 limoneux avec des grains de quartz. Peu de racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à faible.

1.10 FRAGMENT N°10

Fosse 10SO

Localisation : Coordonnée UTM
0235500
7907150
951 m

Topographie : Sommet plus ou moins pointu légèrement à plat sommitaux. Bien drainé. Pente moyenne 31-43% concave.

Végétation : Forêt à structure presque primaire bien fermée 45%, dominée par *Ocotea fotsy*, *Tina striata*, *Canthium* et *Coffea*, d=9-17 cm, h=11-18 m.

Type de sol : sol typique à structure polyédrique (oxisol)

Echantillons : 10CMO, 10CH1, 10CH2

Risque d'érosion : formation de ravin

Description :

Litière plus épaisse (0-21 cm) bien décomposée et plus riche en matière fraîche à la base.

0-47 cm : horizon A brun jaunâtre 10YR5/6 plus jaunâtre à la base, grumeleux, continue à éclats à la base. Très poreux. Enracinement meilleur. Texture argilo-limoneuse. Cohésion moyenne. Transition progressive.

47-87 cm : horizon B1 jaune 10YR7/8, polyédrique à continu, limono-argileux. Cohésion moyenne. Enracinement moyen. Pores moyens. Transition progressive.

87 cm< : horizon B2 sablo-limoneux, jaune brun 10YR6/8. Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 10SBV

Localisation : Coordonnée UTM

0235719

7907941

907 m

Topographie : bas de pente moyenne 27-30%, près ruisseau, drainage moyen.

Végétation : Forêt fermée dominée par *Dombeya*, *Pandanus*, *Ravensara*, *Croton*, *phragmites*, *Harungana*, d=10-35 cm, h=7-19 m

Type de sol : sol ferrallitique rajeuni (ultisol)

Echantillons : 10MO, 10H1, 10H2

Description :

Litière épaisse plus décomposée.

0-11 cm : horizon A peu épais brun 10YR5/3, grumeleux, bien poreux. Enracinement bien développé. Texture limono-argileuse. Cohésion moyenne. Transition progressive.

11-38 cm : horizon B1 jaune brun sombre, polyédrique à continu, pores moyens, limono-sableux. Cohésion moyenne. Enracinement moyen. Transition progressive.

38 cm< : horizon B2 limono-sableux, jaune brun 10YR5/8. Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 10ESO

Localisation : Coordonnée UTM

0235763

7907139

935 m

Topographie : Sommet à replat sommital réduit, bien drainé. Pente 31-43% concave plus ou moins rectiligne.

Végétation : Forêt secondaire fermée à *Ocotea*, *Calophyllum* et *Syzygium*, d=21-47 cm, h=17-24 m.

Type de sol : sol peu évolué (entisol)

Echantillons : 10SoMo, 10SOH1, 10SOH2

Description :

Litière fraîche plus ou moins développée plus épaisse (0-13 cm)

0-27 cm : horizon A brun sombre 7,5YR3/2, grumeleux, continue à éclats à la base. Présence de moyennes racines horizontales à la base. Texture limono-argileuse. Cohésion moyenne. Transition à tendance brusque.

27 cm< : horizon B1 jaune rougeâtre 5YR7/6, polyédrique à continu, limoneux. Cohésion faible. Enracinement moyenne. Transition progressive.

Fosse 10BF

Localisation : Coordonnée UTM

0235805

7907002

958 m

Topographie : bas de pente abrupt (60%), près ruisseau

Végétation : Forêt à structure bien fermée dominée par *Cymbopogon* et *Faucherea*, d=10-23 cm, h=9-16 m.

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 10EMO, 10EH1, 10EH2

Risque d'érosion : formation de ravin et lavaka de faible profondeur

Description :

Litière bien décomposée et moyennement épaisse (0-6 cm)

0-17 cm : horizon A brun sombre 7,5YR4/2, grumeleux, continue à éclats à la base. Très poreux. Bonne pénétration. Texture limono-argileuse. Cohésion moyenne.

17-39 cm : horizon B1 brun clair 7,5YR5/8, polyédrique bien développé, limono-sableux. Cohésion moyenne. Enracinement moyen. Transition progressive.

39 cm< : horizon B2 limono-argileux, jaune rougeâtre 7,5YR7/8. Grosses racines. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

1.11 FRAGMENT N°11

Fosse 11

Localisation : Coordonnée UTM
0236184
7907375

Topographie : Pente 39-41% exposée à l'Est. Bien drainé.

Végétation : Forêt à structure fermée dominée par *Syzygiumla*, *Olex emirnensis*, *Xylopa buxifolia*, *Anthocleista*, et *Uapaca*, d= 9-23 cm, h=13-21m.

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 11MO, 11H1, 11H2

Risque d'érosion : formation de ravin

Description :

Litière bien développée et plus épaisse (0-18 cm)

0-36 cm : horizon A brun sombre 7,5YR4/6, grumeleux, continue à éclats à la base. Bon développement des racines. Très poreux. Texture sablo-limoneuse. Friable et meuble.

36-53 cm : horizon B1 jaune rougeâtre 5YR5/6, polyédrique à continu, limono-sableux, très poreux. Friable et peu meuble. Enracinement moyen. Transition progressive.

53 cm< : horizon B2 limoneux, rouge clair 10R6/8. Grosse racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 11MV(N)

Localisation : Coordonnée UTM

0236074

7907526

917 m

Topographie : pente abrupte 47-67%), bien drainé, rectiligne plus ou moins concave exposée au NE.

Végétation : Forêt d'*Eucalyptus* à structure ouverte 35%, environ 4 ans, d=4-14 cm, h=6-9 m

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 11MVMO, 11MVH1, 11MVH2

Description :

Litière mince (0-2 cm) riche matière fraîche mal décomposée.

0-26 cm : horizon A brun sombre 7,5YR4/6, grumeleux, très poreux. Racines bien développées. Texture limono-sableux. Cohésion moyenne. Transition progressive à tendance brusque .

26-43 cm : horizon B1 gris brun (pinkish gray) 7,5YR6/2, polyédrique peu développé, limono-sableux. Meuble et friable. Peu à moyen poreux. Enracinement moyen. Transition progressive.

43 cm : horizon B2 limono-argileux, rouge clair 2,5YR6/6, grosses racines. Structure continue. Peu poreux. Cohésion moyenne.

Fosse 11SO

Localisation : Coordonnée UTM

0236319

7907368

936 m

Topographie : Sommet pointu à pente plus ou moins rectiligne (39-47%), bien drainé.

Végétation : Forêt de transition : naturelle en mono spécifique d'*Eucalyptus*, Structure plus ou moins fermée (40%), d=10-17 cm, h=9-16 m.

Type de sol : sol typique à structure polyédrique (oxisol)

Echantillons : 11SOMO, 11SOH1, 11SOH2

Description :

Litière bien décomposée riche en tige.

0-57 cm : horizon A brun jaunâtre 10YR5/8, grumeleux, continue à éclats à la base. Présence de moyennes racines horizontales à la base. Texture limono-sableux. Cohésion moyenne ; très poreux. Transition progressive.

57-84 cm : horizon B1 gris brun (pinkish gray) 7,5YR6/2, polyédrique à continu, limono-sableux. Friable et meuble. Enracinement moyenne. Transition progressive.

84 cm< : horizon B2 limoneux avec des concrétions et des stones-lines. Sans racine. Structure polyédrique à continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 11S

Localisation : Coordonnée UTM

0236517

7907247

905 m

Topographie : bas de pente moyenne 37-43%, près ruisseau, bien à moyen drainé

Végétation : Savoka à *Rubis nicolus*, *Clidemia hirta*, Fougère environ 3ans.

Type de sol : sol ferrallitique rajeuni (ultisol)

Echantillons : 11SMO, 11SH1, 11SH2

Risque d'érosion : formation de ravin et lavaka de faible profondeur sur pente raide

Description :

Litière bien décomposée

0-48 cm : horizon A brun clair 7,5YR4/6, grumeleux, continue à éclats à la base. Enracinement bien développé. Pores moyens. Texture limono-argileuse. Cohésion moyenne . Transition progressive.

48-76 cm : horizon B1 rosâtre 7,5YR7/4, polyédrique bien développé, limono-sableux. Très poreux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

76 cm< : horizon B2 limono-argileux, rouge 2,5YR4/8. Grosse racine et riche en chevelus. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 11W

Localisation : Coordonnée UTM
0236057
7907386
916 m

Topographie : pente abrupte 39-51%, concave exposée au NW, bien à moyen drainé.

Végétation : Forêt moyennement fermée (40%), dominée par *Ocotea Hazoporetika*, *Faucherea*, *Macaranga*, *Anthocleista* et *Eucalyptus*, d=10-15 cm, h=11-14 m.

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 11WMO, 11WH1, 11WH2

Risque d'érosion : formation de ravin et lavaka de faible profondeur sur pente raide

Description :

Litière riche en matière fraîche peu décomposée et épaisse.

0-38 cm : horizon A brun rougeâtre 7,5YR5/2, grumeleux, Moyennement poreux (fins). Racines bien développées. Texture argilo-sasbleux. Friable et meuble. Transition progression.

38-57 cm : horizon B1 brun clair 7,5YR4/6, polyédrique à continu, Sablo-limoneux. Pores moyens. Cohésion un peu forte. Enracinement moyen. Transition progressive.

57 cm< : horizon B2 limono-sableux, brun jaunâtre 7,5YR6/8. Racines bien développées. Structure continue à éclats. Moyennement poreux. Cohésion moyenne à forte.

1.12 FRAGMENT N°12

Fosse 12WMV

Localisation : Coordonnée UTM
0237027
7906620
902 m

Topographie : pente moyenne légèrement rectiligne 19% exposée au SE, bien à moyen drainé, près de ruisseaux.

Végétation : Forêt plus ou moins éclairée 30%, dominée par *Syzygiumla*, *Ola*
emirnsensis, *Calophyllum* et *Harungana*, d=9-12 cm, h=8-14 m.

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 12WMVMO, 12WMVH1, 12WMVH2, 12WMVH3

Risque d'érosion : formation de ravin, rigole et lavaka de faible profondeur

Description :

Litière bien décomposée et épaisse

0-27 cm : horizon A brun jaunâtre 10YR5/8, grumeleux, très poreux. Enracinement moyennement développé. Texture sablo-limoneux. Cohésion moyenne. Transition progressive.

27-41 cm : horizon B1 jaune 10YR7/8, polyédrique à continu, argilo-limoneux. Friable et meuble. Enracinement moyen. Transition progressive.

41-70 cm : horizon B2 Limono-argileux, rouge vive 7,5R3/8. Peu de racine (grosse). Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

70 cm< : horizon BC limoneux, rouge clair 7,5R6/8, peu poreux, pas de racine. Structure continue. Cohésion moyenne à forte.

Fosse 12SO

Localisation : Coordonnée UTM

0236944

7906773

891 m

Topographie : Sommet pointu, bien drainé.

Végétation : Forêt à *Anthocleista*, *Xylopia buxifolia*, *Syzygium*, *Uapac*, *Harungana*, structure fermée 45%, d=12-23 cm, h=15-21 m.

Type de sol : sol typique à structure polyédrique (oxisol)

Echantillons : 12SOMO, 12SOH1, 12SOH2

Description :

Litière peu épaisse bien composée et riche en matière fraîche à la base.

0-37 cm : horizon A brun sombre 7,5YR4/4, grumeleux, continue à éclats à la base. Très poreux. Texture sablo-limoneuse. Cohésion moyenne. Transition progressive.

37-46 cm : horizon B1 brun clair 7,5YR5/8, polyédrique, limono-sableux. Cohésion un peu forte. Pores moyens. Enracinement moyen. Transition progressive.

46-74 cm : horizon B2 sablo-limoneux, rouge clair 10R6/8. Enracinement moyen. Structure polyédrique à continue. moyennement poreux. Cohésion moyenne.

Fosse 12S

Localisation : Coordonnée UTM

0233729

7906351

896 m

Topographie : bas de pente 33% de raccord sur bas-fonds, près ruisseau, moyennement drainé

Végétation : Savoka environ 1 an dominé par *Rubis nicolus*, *Dombeya* et d'*Eucalyptus* dispersé de taille d=5-11 cm, h=2-3 m

Type de sol : sol typique à structure polyédrique (oxisol)

Echantillons : 12SMO, 12SH1, 12SH2

Description :

Litière mince riche en matière sèche mal décomposée

0-37 cm : horizon A brun sombre 7,5YR4/2, grumeleux, continue à éclats à la base. Racines très réduites. Texture limono-argileuse. Moyennement poreux. Cohésion moyenne .

37-65 cm : horizon B1 jaune brun 7,5YR7/6, polyédrique à continu, limono-argileuse. Pores moyens. Cohésion un peu forte. Enracinement moyen dressé horizontalement à la base. Transition progressive.

65 cm< : horizon B2 limoneux avec des grains de quartz et de blocs (4-16 cm) de roche plus ou moins altérée granitique. Sans racine. Structure lamellaire à éclats. Peu poreux. cuirasse.

1.13 FRAGMENT N°13

Fosse 13EMV

Localisation : Coordonnée UTM
0237493
7906409
457 m

Topographie : Versant de pente moyenne 21-39% concave plus ou moins rectiligne, bien drainé.

Végétation : Forêt à structure primaire bien fermée, dominée par *Uapaca*, *Anthocleista*, *Syzygiumla* et *Eucalyptus*, d=12-23 cm, h=9-21 m.

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 13EMVMO, 13EMVH1

Description :

Litière bien décomposée et peu épaisse

0-31 cm : horizon A brun sombre 7,5YR5/8, grumeleux, continue à éclats à la base, très poreux. Racines verticales bien développées. Texture sablo-limoneuse. Friable et meuble.

31 cm< : horizon B1 jaune brun 10YR5/8, continu à tendance polyédrique, limoneux. Cohésion un peu forte. Enracinement moyenne.

Fosse 13SO

Localisation : Coordonnée UTM
0237423
7906397
576 m

Topographie : sommet aiguë à pente 36-43% concave bien drainé.

Végétation : Forêt à structure bien fermée 55%, dominée par *Uapaca*, *Syzygiumla*, *Ravensara*, *Hetatra*, *Mammea madagascariensis* et *Bamboo*, d=8-12 cm, h=9-14 m.

Type de sol : sol typique à structure polyédrique (oxisol)

Echantillons : 13SOMO, 13SOH1, 13SOH2, 13SOH3

Description :

Litière bien décomposée et plus épaisse 0-21 cm

0-39 cm : horizon A brun sombre 7,5YR5/6, grumeleux, continue à éclats à la base. Présence de moyennes racines horizontales à la base. Texture sablo-limoneuse. Cohésion moyenne .

39-57 cm : horizon B1 jaune brun 5YR6/8, polyédrique à continu, sablo-limoneuse. Cohésion un peu forte. Enracinement moyen. Pores moyens. Présence de cuirasse (blocs de migmatite 15 à 30 cm). Transition progressive.

57-82 cm : horizon B2 sablo-limoneuse, brun rougeâtre 5YR6/4. Pores moyens. Sans racine. Structure polyédrique à continue. Cohésion moyenne à forte. Transition progressive.

82 cm< : horizon BC argilo-limoneux, brun grisâtre 7,5YR6/2, structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 13N

Localisation : Coordonnée UTM

0237342

7906519

Topographie : Pente 27-34%, concave exposée au N, bien à moyen drainé.

Végétation : Savoka récente avec quelques pieds d'*Eucalyptus* (1an), dominée par *Dombeya*, *Rubis nicolus*, *Clidemia hirta*. (h=1-3 m)

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 13NMO, 13NH1, 13NH2

Description :

Litière plus ou moins décomposée et moyennement épaisse

0-32 cm : horizon A brun sombre 7,5YR4/6, grumeleux, moyennement poreux. Racines bien développées. Texture limono-sableuse. Cohésion moyenne. Transition progressive.

32-67 cm : horizon B1 gris brun 7,5YR6/2 (Pinkish gray), polyédrique à continu, limono-sableux. Cohésion un peu forte. Enracinement moyen. Pores fines. Transition progressive.

67 cm< : horizon B2 limoneux, rouge clair 2,5YR6/8. Peu de racine. Structure continue. Peu poreux. Cohésion moyenne à forte.

Fosse 13S

Localisation : Coordonnée UTM

0237520

7906257

Topographie : bas de pente 31-43% concave exposée au sud, près ruisseau, moyennement drainé.

Végétation : Forêt à structure très bien fermée (70%), dominée par Erythroxylum, Mammea madagascariensis, Syzygiumla et Hetatra. D=16-27 cm, h=13-15 m.

Type de sol : sol jaune sur rouge à rajeuni (ultisol/entisol)

Echantillons : 13SMO, 13SH1, 13SH2

Description :

Litière plus ou moins décomposée et épaisse

0-34 cm : horizon A brun jaunâtre 10YR5/8, grumeleux, continue à éclats à la base.. Texture sablo-argileuse. Très poreux. Cohésion moyenne.

34-49 cm : horizon B1 jaune 10YR7/8, polyédrique à continu, limono-argileux. Présence de moyennes racines horizontales à la base. Peu poreux. Cohésion un peu forte. Transition progressive.

49 cm <: horizon B2 limoneux avec des grains de quartz et de granite (concrétions). Peu de racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 13W

Localisation : Coordonnée UTM

0237348

7906419

Topographie : pente moyenne à abrupte 37-61%, bien drainé.

Végétation : Forêt naturelle à *Mammea madagascariensis* de transition avec savoka et *Eucalyptus*

Type de sol : sol typique à structure polyédrique (oxisol)

Echantillons : 13WMO, 13WH1, 13WH2

Description:

Litière riche en matière fraîche peu ou mal décomposée et moins épaisse

0-39 cm : horizon A brun sombre 7,5YR4/2, grumeleux, continue à éclats à la base. Enracinement bon surtout à la surface supérieure. Texture limono-sableuse. Cohésion moyenne.

39-61 cm : horizon B1 jaune brun 7,5YR7/6, polyédrique à continu, limono-argileux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

61 cm< : horizon B2 limoneux. Peu de racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

1.14 FRAGMENT N°14

Fosse 14N

Localisation : Coordonnée UTM
0238520
7906885
862 m

Topographie : pente abrupte 35-61%, bien à moyen drainé.

Végétation : Forêt à *Mammea madagascariensis*, à *Eucalyptus* et *Rubis nicolus*.
d=11-31 cm, h=16-21 m.

Type de sol : sol typique à structure polyédrique (oxisol)

Echantillons : 14NMO, 14NH1, 14NH2

Description :

Litière plus ou moins décomposée et riche matière fraîche moins ou mal décomposée à la base.

0-39 cm : horizon A brun clair 7,5YR4/6, grumeleux, continue à éclats à la base. Très bien poreux. Texture limono-sableuse. Friable et meuble. Enracinement bon. Transition progressive.

39-74 cm : horizon B1 gris brun 7,5YR6/2 (pinkish gray), polyédrique peu développé, Limono-sableux. Très poreux. Cohésion moyenne. Enracinement moyen. Transition progressive.

74 cm < : horizon B2 limoneux. Rouge clair 2,5YR6/8. Racines peu réduites. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 14E

Localisation : Coordonnée UTM
0238106
7906358

Topographie : pente abrupt 24-37% exposée NW et SE, près ruisseau, moyen drainé.

Végétation : Forêt d'*Eucalyptus* taillis 6 ans moins dense (60%), d=12-24 cm, h=4-6 m.

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 14EMO, 14EH1, 14EH2

Risque d'érosion : Formation de ravin, de rigole et lavaka peu profnds. (Dégradation de surface causée par les trous-charbons).

Description :

Litière mince plus ou moins décomposée

0-35 cm : horizon A brun jaunâtre 10YR5/8, grumeleux, continue à éclats à la base. Présence de moyennes racines horizontales à la base. Texture sablo-argileuse. Cohésion moyenne.

35-57 cm : horizon B1 jaune 10YR7/8, polyédrique à continu, limono-sableux. Moyennement poreux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

57 cm < : horizon B2 rouge clair 10R6/8, limoneux avec des grains de quartz. Peu de racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 14S

Localisation : Coordonnée UTM

0238112

7906187

Topographie : pente abrupte 37-51% concave exposée au sud, bien drainé.

Végétation : Forêt secondaire à *Mammea madagascariensis*, *Uapaca*, *Olax emirnensis* et *Brachylaena*, structure plus ou moins ouverte 55%, d=12-37 cm, h=11-18m.

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 14SMO, 14SH1, 14SH2

Description :

Litière à épaisseur moyenne bien décomposée

0-31 cm : horizon A brun jaunâtre 10YR5/8, grumeleux, bien poreux. Enracinement bien développé. Texture sablo-limoneuse. Friable et meuble. Transition progressive.

31-44 cm : horizon B1 jaune 10YR7/8 polyédrique à continu, limono-argilo. Cohésion un peu forte. Enracinement moyen à faible. Transition progressive.

44 cm < : horizon B2 limoneux des grains de quartz plus ou moins cubique. Sans grosse racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 14SO

Localisation : Coordonnée UTM

0237791

7906423

Topographie : Sommet plus ou moins étroit à pente abrupte 41-45% concave, bien drainé. Exposée à l'W

Végétation : Forêt naturelle à structure primaire au Sud et Forêt d'*Eucalyptus* à l'Est d=9-41 cm, 9-19m.

Type de sol : sol typique à structure polyédrique (oxisol)

Echantillons : 14SOMO, 14SOH1, 14SOH2

Description :

Litière épaisse bien décomposée et très riche en matière fraîche bien développée.

0-42 cm : horizon A brun clair 7,5YR4/6, grumeleux, continue à éclats à la base. Très bien poreux. Texture sablo-limoneuse. Très bon développement des racines. Cohésion moyenne.

42-67 cm : horizon B1 jaune brun 5YR5/6, polyédrique peu développée à continu, limono-sableux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

67 cm < : horizon B2 limoneux avec des grains de quartz (concrétions). Riche en chevelue racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

1.15 FRAGMENT N°15

Fosse 15E

Localisation : Coordonnée UTM
0238556
7906313

Topographie : pente abrupte 45-64% concave, bien drainé.

Végétation : Savoka à *Eucalyptus* (d=4-16 cm, h=8-16 m)- Transition vers en savoka dominée par *Heteropogon* et *Aframomum*.

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 15EMO, 15EH1, 15EH2, 15EH3

Risque d'érosion : Formation de rigole et ravin peu profond.

Description :

Litière mince plus ou moins décomposée

0-17 cm : horizon A brun clair 7,5YR5/8, grumeleux, continue à éclats à la base. Présence de moyennes racines à tendance dressée horizontalement à la base. Texture argilo-sableuse. Présence des concrétions et des stones-lines. Cohésion moyenne . Transition progressive.

17-34 cm : horizon B1 jaune brun 7,5YR6/8, polyédrique plus ou moins continu, Sablo-limoneux. Très bien poreux. Cohésion un peu forte. Enracinement dressé horizontal et réduit. Présence de nombreuses concrétions et des stones-lines sous forme de cuirasse (4-10 cm) que l'horizon supérieur. Transition progressive.

34-74 cm : horizon B2 rouge 7,5YR4/8, sablo-limoneux avec des grains de mica et de quartz. Peu de racine. Structure polyédrique à continue à éclats. Moyennement poreux. Cohésion moyenne à forte.

74 cm < : horizon BC sablo-limoneux, rouge clair 7,5R6/8, Pores moyens. Sans racine. Cohésion moyenne à forte.

Fosse 15N

Localisation : Coordonnée UTM

0238409

7906382

Topographie : pente 36-41% concave, moyen drainé, près ruisseau.

Végétation : Forêt dégradée par les feux il y avait 1 an.

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 15NMO, 15NH1, 15NH2

Risque d'érosion : Formation de ravin et lavaka peu profond.

Description :

Litière plus ou moins épaisse et matière fraîche bien décomposée

0-49 cm : horizon A brun clair 7,5YR4/6, grumeleux, à éclats à la base. Enracinement très bien développé. Texture limono-sableuse . Très poreux. Cohésion moyenne.

49-75 cm : horizon B1 gris brun, polyédrique à continu, limoneux. Cohésion un peu forte. Enracinement moyen. Peu poreux. Transition progressive.

75 cm < : horizon B2 limono-argileux avec des grains de pisolite (migmatite). Sans racine. Structure continue à éclats. Pores moyen. Cohésion moyenne à forte.

Fosse 15S

Localisation : Coordonnée UTM

0238317

7906190

Topographie : pente abrupte 65-71% concave, près de Chute d'eau.

Végétation : Forêt secondaire plus ou moins perturbée à structure ouverte (35%), dominée par à *Faucherea*, *Ramy*, *Ocotea*, *Mammea madagascariensis*, *Canthium*, *Anthocleista* et *Wenmenia* ; d=16-29 cm, h=13-21 m.

Type de sol : sol typique à structure polyédrique (oxisol)

Echantillons : 15SMO, 15SH1, 15H2

Risque d'érosion : Formation de rigole, ravin et lavaka peu profond.

Description :

Litière bien décomposée

0-37 cm : horizon A gris brun 7,5YR6/2, grumeleux, Très poreux. Texture limono-sableuse. Très bonne pénétration des racines. Cohésion moyenne. Transition progressive.

37-81 cm : horizon B1 jaune brun 7,5YR7/6, polyédrique à continu, limono-sableux. Pores moyens. Cohésion un peu forte. Enracinement moyen. Transition progressive.

81 cm < : horizon B2 limoneux, rouge 2,5YR6/8. Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 15W

Localisation : Coordonnée UTM

0238249

7906241

Topographie pente moyennement abrupt 37-45% exposée au NE et au SW, moyen drainé.

Végétation : Forêt à structure ouverte 30%, dominée par *Canthium*, *Wenmenia*, *Erythroxylum* (d=7-31 cm, h=9-14 m), en transition avec forêt d'Eucalyptus (d=6-16 cm, h=10-17 m)

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 15WMO, 15WH1, 15WH2

Risque d'érosion : Formation de rigole et ravin peu profond.

Description :

Litière épaisse (0-6 cm) bien décomposée.

0-38 cm : horizon A gris brun 7,5YR6/2, grumeleux, continue à éclats à la base. Très bien poreux. Bonne pénétration des racines. Texture limono-argileuse. Cohésion moyenne . Transition progressive.

38-51 cm : horizon B1 jaune brun 7,5YR7/6, polyédrique à continu, limono-argileux. Pores moyens. Cohésion un peu forte. Enracinement moyen. Transition progressive.

51 cm < : horizon B2 limono-sableux avec des grains de quartz. Peu de racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 15SO

Localisation : Coordonnée UTM

0238453

7906320

Topographie : Sommet plus ou moins aiguë à pente faible 21- 27%, bien drainé.

Végétation : Forêt à structure bien fermée 65%, dominée par *Ocotea*, *Filicium*, *Canthium*, *Coffea*, *Wenmenia* et *Phramites* ; d= 12-34 cm, h=11-22 m.

Type de sol : sol typique à structure polyédrique (oxisol)

Echantillons : 15SOMO, 15SOH1, 15SOH2

Risque d'érosion : Formation de ravin et érosion en nappe peu profond.

Description :

Litière épaisse riche en matière fraîche peu ou mal décomposée.

0-17 cm : horizon A brun jaunâtre 7,5YR6/6, grumeleux bien développé, très poreux. Enracinement bien développé. Texture sablo-limoneuse avec des grains de quartz (concrétions). Cohésion moyenne.

17-53 cm : horizon B1 gris brun 7,5YR7/2, polyédrique bien développée, limono-sableux. Très poreux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

53 cm < : horizon B2 limono-argileux avec des grains de quartz. Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

2 TRANSECT D'ANKODROMORONA

Fosse 1b

Localisation : Coordonnée UTM
0239387
7911745
702 m

Topographie : sommet pointu à pente abrupte 65-74% concave et bien drainé.

Végétation : Savoka à *Fougère*, *Arundinella* et *Psidium*.

Type de sol : sol peu évolué d'érosion (entisol)

Echantillons : 1bMO, 1bH1, 1bH2

Description :

Litière bien décomposée

0-9 cm : horizon A peu épais brun sombre 7,5YR4/6, grumeleux, continue à éclats à la base. Très bien poreux. Racines bien développées. Texture limono-argileuse. Cohésion moyenne. Transition brusque.

9-54 cm : horizon B1 rosâtre, polyédrique à continu, limono-argileux, micacé sous forme des concrétions. Cohésion un peu forte. Enracinement moyen. Transition progressive.

54 cm < : horizon B2 limoneux micacé, rouge 2,5YR4/8. Peu de racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 2b

Localisation : Coordonnée UTM

0239398

7911663

694 m

Topographie : pente moyenne 14% concave plus ou moins rectiligne exposée au N, bien drainé.

Végétation : Forêt d'*Eucalyptus* environ 6 à 8 ans à structure ouverte 25%, d=6-31 cm, h=4-21 m.

Type de sol : sol peu évolué d'érosion (entisol)

Echantillons : 2bMO, 2bH1, 2bH2

Description :

Litière bien décomposée

0-27 cm : horizon A brun sombre 7,5YR3/4, grumeleux, continue à éclats à la base. Très poreux. Bon enracinement. Texture limono-sableuse. Présence des concrétions de quartz (Fins- particulières). Cohésion moyenne. Transition progressive.

27-57 cm : horizon B1 jaune brun 7,5YR6/8, polyédrique à continu, limoneux. Pores moyens. Cohésion un peu forte. Enracinement moyen. Transition progressive.

57 cm < : horizon B2 limono-argileux, rouge 7,5R6/8, avec des particules de mica. Peu de racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 3b

Localisation : Coordonnée UTM

0239380

7911618

667 m

Topographie : pente 19% concave exposée au N, moyen drainé.

Végétation : *Heteropogon*, *Cyclosorus* et *Arundinella*.

Type de sol : sol jaune brun sur rouge avec concrétions (ultisol)

Echantillons : 3bMO, 3bH1, 3bH2

Description :

Litière plus ou moins décomposée

0-13 cm : horizon A brun sombre 7,5YR3/2, grumeleux bien développé, continue à éclats à la base. Très bon développement des racines. Très bien poreux. Texture limono-sableuse. Cohésion moyenne. Transition progressive.

13-81 cm : horizon B1 jaune brun 7,5YR6/6, polyédrique à continu, limono-sableux, micacé et des concrétions de quartzite. Pores moyens. Cohésion moyenne à forte. Enracinement moyen. Transition progressive.

81 cm < : horizon B2 rouge 2,5YR6/8, limoneux plus riche en mica que l'horizon supérieur. Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 4b

Localisation : Coordonnée UTM

0239379

7911506

714 m

Topographie : pente plus ou moins abrupte 43-65% exposée au NE vers SW, bien à moyen.

Végétation : *Eucalyptus* et *Dombeya* ouvert 25%, d=9-27 cm, h=12-17 m

Type de sol : sol ferrallitique jaune brun (ultisol)

Echantillons : 4bMO, 4bH1, 4bH2

Description :

Litière épaisse bien décomposée et mal développée à la base.

0-38 cm : horizon A brun sombre 7,5YR3/2, grumeleux bien développé. Bon enracinement. Très bien poreux. Texture limono-sableuse. Cohésion moyenne. Transition progressive.

38-76 cm : horizon B1 brun clair 7,5YR4/6, polyédrique à continu, limono-sableux. Poreux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

76 cm < : horizon B2 limoneux, jaune brun 7,5YR7/6. Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 5b

Localisation : Coordonnée UTM

0239364

7911426

671 m

Topographie : bas de pente moyenne 43-51%, bien drainé.

Végétation : Savoka à structure bien fermée 65% environ 3 à 4 ans, dominée par *Cyclosorus*, *Arundinella* et *Clidemia hirta*.

Type de sol : sol jaune typique à structure polyédrique (ultisol)

Echantillons : 5bMo, 5bH1, 5H2

Risque d'érosion : Formation de ravin et lavaka peu profond.

Description :

Litière mince riche en matière fraîche peu ou mal décomposée.

0-33 cm : horizon A brun jaunâtre 7,5YR3/2, grumeleux développé, très poreux. Enracinement bien développé. Texture sablo-limoneuse avec des grains de quartz (concrétions de migmatite). Cohésion moyenne .

33-45 cm : horizon B1 jaune brun 7,5YR6/6, polyédrique bien développée, limono-sableux, micacé. Très poreux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

45 cm < : horizon B2 rouge jaunâtre 7,5YR6/8, limoneux plus micacé que l'horizon supérieur. Peu de racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 6b

Localisation : Coordonnée UTM

0239354

7911326

712 m

Topographie : pente abrupte 65% convexe exposée à l'Est, bien drainé.

Végétation : savoka à *Hypparhenia rufa* et *Psidium*.

Type de sol : sol ferrallitique jaune brun sur rouge (ultisol)

Echantillons : 6bMO, 6bH1, 6bH2

Risque d'érosion : Formation de trace de ravin peu profond.

Description :

Litière mince et de matière fraîche peu ou mal décomposée.

0-19 cm : horizon A brun 7,5YR4/4, grumeleux bien développé, très poreux. Enracinement moyennement développé. Texture limono-sableuse avec peu nombreux des grains de quartz (concrétions). Cohésion moyenne. Transition brusque.

19-58 cm : horizon B1 jaune brun 7,5YR6/8, polyédrique bien développée, limono-sableux avec des concrétions de quartz bien marquées (5-17 cm). Très poreux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

58 cm < : horizon B2, rouge clair 2,5YR6/6, limoneux avec des mica sous forme lamellaire (fine). Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 7b

Localisation : Coordonnée UTM

0239363

7911224

742 m

Topographie : Pente convexe plus ou moins rectiligne variant de 26-43%, bien drainé

Végétation : Savoka dominée par *Hypparhenia rufa*, *Fougère* et *Radriaka*.

Type de sol : sol jaune brun sur rouge jaunâtre (ultisol)

Echantillons : 7bMO, 7bH1, 7bH2

Risque d'érosion : Formation de trace de ravin peu profond.

Description :

Litière peu épaisse riche en matière fraîche peu ou mal décomposée.

0-21 cm : horizon A brun 7,5YR4/2, grumeleux bien développé, continu à la base, très poreux. Enracinement bien développé. Texture limono-argileuse. Cohésion moyenne.

21-62 cm : horizon B1 jaune brun 7,5YR6/8, polyédrique bien développée, limono-sableux, moyennement micacé à la base. Très poreux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

62 cm < : horizon B2 rouge clair 2,5YR6/8, limoneux très riche en mica. Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 8b

Localisation : Coordonnée UTM
0239506
7911897
770 m

Topographie : Pente abrupte concave exposée au N et au S 67- 77%, bien à moyen drainé.

Végétation : Forêt à structure bien fermée 65%, dominée par *Anthocleista*, *Arofy*, *Ramy et Hazoporetika* ; d= 16-43 cm, h=19-24 m.

Type de sol : sol jaune brun sur rouge (ultisol)

Echantillons : 8bMO, 8bH1, 8bH2

Risque d'érosion : Formation de trace de ravin et d'érosion en lavaka peu profond surtout suivant les layons..

Description :

Litière épaisse bien décomposée.

0-53 cm : horizon A épais brun sombre 7,5YR3/2, grumeleux bien développé, très poreux. Enracinement bien développé. Texture limono-sableuse. Cohésion moyenne. Transition progressive.

53-78 cm : horizon B1 brun 7,5YR4/4, polyédrique bien développée, limono-sableux. Très poreux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

78 cm < : horizon B2 rouge vif 7,5YR3/6, sablo-limoneux avec des grains de quartz et de granite. Sans racine. Structure polyédrique à continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 9b

Localisation : Coordonnée UTM

023

7911

Topographie : pente moyenne 45-63% exposée à l'ouest, bien drainé.

Végétation : Savoka dominé par *Fougère*, *Dombeya* et *Clidemia hirta*.

Type de sol : sol peu évolué d'érosion jaune sur rouge avec de stone-lines (entisol)

Echantillons : 9bMO, 9bH1, 9bH2

Risque d'érosion : Formation de ravin et érosion en lavaka peu profond.

Description :

Litière épaisse riche en matière fraîche peu ou mal décomposée.

0-18 cm : horizon A brun sombre 7,5YR3/4, grumeleux bien développé, très poreux. Enracinement bien développé. Texture limono-argileuse. Cohésion moyenne.

18-63 cm : horizon B1 brun clair 7,5YR5/6, polyédrique peu développée, sablo-limoneux moyennement micacé. Moyennement poreux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

63 cm < : horizon B2 sablo-limoneux avec des concrétions voire des stones lines de roche altérée (migmatite de taille 4-12 cm). Sans racine. Structure polyédrique à tendance continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 10b

Localisation : Coordonnée UTM

48°31'33,7''

18°52'05,4''

Topographie : Pente moyenne 37-42%, bien drainé.

Végétation : Savoka à *Fougère*, *Arundinella* et *Albizia*.

Type de sol : sol peu évolué jaune brun sur rouge (entisol)

Echantillons : 10bMO, 10bH1, 10bH2

Risque d'érosion : Formation de ravin peu profond.

Description :

Litière épaisse riche en matière fraîche peu ou mal décomposée.

0-11 cm : horizon A brun sombre 7,5YR4/6, grumeleux bien développé, très poreux. Enracinement bien développé. Texture limono-argileuse. Cohésion moyenne. Transition brusque.

11-52 cm : horizon C1 brun rosâtre 7,5YR7/4, polyédrique fine mal développée à tendance continue, limono-argileux micacé. Très poreux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

52 cm < : horizon C1 rouge vif 2,5YR4/8, limoneux très riche en mica que l'horizon supérieur. Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 11b

Localisation : Coordonnée UTM

Topographie : Pente assez faible 19-31%, bien drainé.

Végétation : Savoka à Fougère, *Arundinella et Clidemia hirta*

Type de sol : sol typique à structure polyédrique (oxisol)

Echantillons : 11bMO, 11bH1, 11bH2

Risque d'érosion : Formation de ravin peu profond.

Description :

Litière peu épaisse riche en matière fraîche peu ou mal décomposée.

0-18 cm : horizon A brun sombre 7,5YR3/2, grumeleux bien développé, très poreux. Enracinement bien développé. Texture limono-sableuse. Cohésion moyenne. Transition progressive.

18-75 cm : horizon B1 jaune brun 7,5YR6/6, polyédrique bien développée, limono-sableux micacé. Très poreux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

75 cm < : horizon B2 rouge clair 2,5YR6/8, limoneux riche en mica. Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

3 TRANSECT D'AMBOHIMANARIVO

Fosse 1

Localisation : Coordonnée UTM
0239506
7912016
699 m

Topographie : bas-versant à pente 31-47% exposé au N, bien drainé.

Végétation : Savoka à *Fougère*, *Arundinella*, *Tegnina* et *Psidium*

Type de sol : sol typique à structure polyédrique (oxisol)

Echantillons : 1MO, 1H1, 1H2

Risque d'érosion : Sans formation de ravin et érosion.

Description :

Litière épaisse riche en matière fraîche moyennement décomposée.

0-54 cm : horizon A brun sombre 7,5YR4/6, grumeleux à tendance continue surtout à la base, moyennement poreux. Enracinement bien développé. Texture limono-argileuse. Cohésion moyenne à faible. Transition brusque.

54-75 cm : horizon B1 brun rosâtre 7,5YR7/4, polyédrique bien développée, limono-argileux micacé. Très poreux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

53 cm < : horizon B2 rouge 2,5YR4/8 limoneux très riche en mica. Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 2

Localisation : Coordonnée UTM
0239611
7912165
698 m

Topographie : pente faible 14% concave exposée au NS, bien drainé (>55 cm).

Végétation : Forêt en transition avec savoka, dominée par *Eucalyptus*.

Type de sol : sol jaune brun sur rouge concrétionné et micacé (ultisol)

Echantillons : 2MO, 2H1, 2H2

Risque d'érosion : Aucune formation d'érosion.

Description :

Litière plus ou moins épaisse peu décomposée.

0-28 cm : horizon A brun sombre 7,5YR3/4, grumeleux bien développé, très poreux. Enracinement bien développé. Texture *limono-sableuse*. Cohésion moyenne.

28-61 cm : horizon B1 jaune brun 7,5YR6/8, polyédrique bien développée, limono-sableux micacé. Très bien poreux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

61 cm < : horizon B2 rouge 7,5R6/8, limoneux micacé avec des grains de quartz. Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 3

Localisation : Coordonnée UTM
0239618
7912205
710 m

Topographie : pente légèrement faible 27-32%, bien à moyen drainé (>43 cm).

Végétation : Savoka à *Hypparhenia*

Type de sol : sol jaune brun sur rouge micacé et concrétionné (oxisol)

Echantillons : 3MO, 3H1,3H2

Risque d'érosion : Aucune trace de formation d'érosion.

Description :

Litière mince riche en matière fraîche peu ou mal décomposée.

0-27 cm : horizon A brun 7,5YR5/2, grumeleux bien développé, très poreux. Enracinement moyennement développé. Texture limono-argileux avec des grains voire blocs (4-7 cm) de quartz (concrétions). Cohésion moyenne .

27-67 cm : horizon B1 jaune brun 7,5YR7/8, polyédrique à continue à éclats à la base, limono-argileux avec quelques blocs de quartz (10-15 cm). Très poreux. Cohésion un peu forte. Enracinement moyen à faible. Transition progressive.

67 cm < : horizon B2 rouge clair 7,5YR6/8, limoneux riche micacé avec des grains de quartz (fins). Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 4

Localisation : Coordonnée UTM

0239644

7912252

717 m

Topographie : Sommet de ligne de crête raccord vers bas-fonds (ruisseaux) à pente faible 9-14% exposée au NW, bien drainé.

Végétation : Forêt à structure moyennement ouverte 35%, dominée par *Ocotea*, *Filicium*, *Canthium*, *Coffea*, *Wenmenia* et *Phragmites* ; d= 27-40 cm, h=12-23 m.

Type de sol : sol peu évolué d'érosion jaune brun sur rouge concrétionné (oxisol)

Echantillons : 4MO, 4H1, 4H2

Risque d'érosion : Formation de ravin et érosion en lavaka peu profond.

Description :

Litière épaisse riche en matière fraîche bien décomposée.

0-24 cm : horizon A brun sombre 7,5YR3/4, grumeleux bien développé avec très nombreux des résidus de ver de terre, très poreux. Enracinement bien développé. Texture limonoargileuse avec des grains de quartz (concrétions). Cohésion moyenne .

24-38 cm : horizon B1 gris brun 7,5YR7/2, polyédrique bien développée, limono-argileux. Moyennement poreux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

38 cm < : horizon B2, rouge 7,5R4/8, limoneux avec des grains de quartz et peu de Gibbs. Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 5

Localisation : Coordonnée UTM

0239708

7912279

703 m

Topographie : Pente 51% concave exposée à l'W, bien drainé.

Végétation : Savoka récent *Rubis nicolus*, et *Albizia*

Type de sol : sol jaune brun sur rouge (ultisol)

Echantillons : 5MO, 5H1, 5H2

Risque d'érosion : Formation de ravin et érosion en nappe peu profond.

Description :

Litière épaisse riche en matière fraîche bien décomposée.

0-25 cm : horizon A brun sombre 7,5YR3/4, grumeleux bien développé, très poreux. Enracinement bien développé. Texture limono-argileuse. Cohésion moyenne.

25-53 cm : horizon B1 jaune brun 7,5YR6/8, polyédrique à continu à éclats, limono-argileux, micacé (fine). Moyennement poreux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

53 cm < : horizon B2, brun rosâtre 7,5YR8/4, limoneux micacé avec des grains de quartz (concrétions). Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 6

Localisation : Coordonnée UTM

0239680

7912328

676 m

Topographie : Sommet plus ou moins aiguë à pente faible 23- 27%, bien drainé.

Végétation : savoka riche en *Aframomum* et *Clidemia hirta*

Type de sol : sol jaune brun sur rouge micacé et concrétionné (ultisol)

Echantillons : 6MO, 6H1, 6H2

Risque d'érosion : Formation de ravin et érosion en nappe peu profond.

Description :

Litière épaisse riche en matière fraîche peu ou mal décomposée.

0-27 cm : horizon A brun 7,5YR4/4, grumeleux bien développé à continu, très poreux. Enracinement bien développé. Texture limono-argileuse. Cohésion moyenne.

27-54 cm : horizon B1 jaune brun 7,5YR7/2, polyédrique peu développée, tendance continue à la base, limoneux très micacé. Moyennement poreux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

53 cm < : horizon B2 rouge 7,5R5/8, limoneux micacé sous forme lamellaire avec peu des grains de quartz (concrétions). Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 7

Localisation : Coordonnée UTM

0239685

7912418

721 m

Topographie : Bas de pente raide 57% exposée au S, près de ruisseaux, moyen à mal drainé en saison pluvieuse.

Végétation : savoka.

Type de sol : sol typique à structure polyédrique (ultisol)

Echantillons : 7MO, 7H1, 7H2

Risque d'érosion : Formation d'érosion en nappe peu profond.

Description :

Litière épaisse riche en matière fraîche bien décomposée.

0-18 cm : horizon A brun 7,5YR4/4, grumeleux bien développé, moyennement poreux. Enracinement bien développé. Texture limono-argileuse avec des micas fins. Cohésion moyenne.

18-36 cm : horizon B1 brun sombre 7,5YR3/4, polyédrique bien développée, sablo-limoneux micacé. Très poreux. Cohésion un peu forte. Enracinement moyen à tendance dressée horizontalement. Transition progressive.

36 cm < : horizon B2 brun clair 7,5YR6/4, sableux avec des grains de quartz et des blocs basaltiques (5-10 cm). Sans racine. Structure polyédrique à particulaire. Très poreux. Cohésion moyenne à forte.

Fosse 8

Localisation : Coordonnée UTM

0239670

7912465

734 m

Topographie : Pente 37-48% concave exposée au N et à l'E, bien drainé.

Végétation : Savoka dominée par *Clidemia hirta* et *Tegnina*.

Type de sol : sol jaune brun sur rouge jaunâtre micacé et concrétionné (ultisol)

Echantillons : 8MO, 8H1, 8H2

Risque d'érosion : Formation de ravin et érosion en lavaka peu profond.

Description :

Litière plus ou moins épaisse riche en matière fraîche décomposée.

0-27 cm : horizon A brun 7,5YR5/2, grumeleux bien développé, très poreux. Enracinement bien développé. Texture limono-argileuse. Cohésion moyenne.

27-56 cm : horizon B1 jaune brun 7,5YR7/8, polyédrique à tendance continue, limoneux micacé avec des grains de quartz (peu de gibbs). Peu poreux. Cohésion moyenne. Enracinement moyen. Transition progressive.

53 cm < : horizon B2 rouge clair 7,5YR6/8, limoneux très micacé que l'horizon supérieur. Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 9

Localisation : Coordonnée UTM

0239670

7912555

737 m

Topographie : pente 23-32% concave exposée au SE, bien à moyen drainé.

Végétation : savoka semi-dégradée (dispersée) dominée par *Tegnina* et *Fougère*

Type de sol : sol typique à structure polyédrique micacé (oxisol)

Echantillons : 9MO, 9H1, 9H2

Risque d'érosion : Formation de ravin, rigole et lavaka peu profond.

Description :

Litière peu épaisse riche en matière fraîche peu ou mal décomposée.

0-31 cm : horizon A brun sombre 7,5YR4/6, grumeleux bien développé, très poreux. Enracinement bien développé. Texture limono-sableuse micacé finement. Cohésion moyenne.

31-46 cm : horizon B1 jaune brun 7,5YR6/8, polyédrique bien développée, limono-sableux avec des grains de quartz (concrétions). Moyennement poreux. Cohésion moyenne. Enracinement moyen. Transition progressive.

46 cm < : horizon B2 rouge clair 7,5YR6/8, limoneux très micacé. Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 10

Localisation : Coordonnée UTM

0239642

7912746

776 m

Topographie : Pente 47-63% concave exposée au Sud, bien à moyen drainé.

Végétation : Forêt à structure bien fermée 80 %, dominée par *Wenmenia*, *Cymbopogon*, *Dombeya*, *Mammea madagascariensis* et *Syzygium*; d= 19-29 cm, h=9-14m.

Type de sol : sol jaune brun sur rouge micacé et concrétionné (ultisol)

Echantillons : 10MO, 10H1, 10H2

Risque d'érosion : Formation de ravin et lavaka peu profond.

Description :

Litière plus épaisse riche en matière fraîche bien décomposée.

0-37 cm : horizon A brun sombre 7,5YR3/4, grumeleux bien développé, très poreux. Enracinement bien développé. Texture limono-argileuse avec des pellicules de mica. Cohésion moyenne . Transition progressive.

37-82 cm : horizon B1 rouge 7,5YR4/8, polyédrique bien développée, limono-sableux avec des grains de quartz et micacé. Très poreux. Cohésion moyenne. Enracinement moyen. Transition progressive.

82 cm < : horizon B2 rouge clair 7,5R6/8, limoneux avec des grains de quartz. Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

Fosse 11

Localisation : Coordonnée UTM

18°51'32, 5''

48°31'42, 0''

776 m

Topographie : Sommet plus ou moins aiguë à pente forte 54% concave, bien drainé.

Végétation : Savoka *Clidemia hirta et Tegnina*

Type de sol : sol typique à structure polyédrique micacé et concrétionné (oxisol)

Echantillons : 11MO, 11H1, 11H2

Risque d'érosion : Formation d'érosion en nappe peu profond.

Description :

Litière épaisse riche en matière fraîche bien décomposée.

0-17 cm : horizon A brun jaunâtre 7,5YR6/6, grumeleux bien développé, très poreux. Enracinement bien développé. Texture sablo-limoneuse. Cohésion moyenne.

17-53 cm : horizon B1 gris brun 7,5YR7/2, polyédrique bien développée, limono-sableux micacé. Très poreux. Cohésion un peu forte. Enracinement moyen. Transition progressive.

53 cm < : horizon B2 limono-argileux très micacé. Sans racine. Structure continue à éclats. Peu poreux. Cohésion moyenne à forte.

TABLEAU RECAPITULATIF
DE TYPES DE SOLS

Tableau 1 Tableau Recapitulatif De Types De Sols

Site	Fosse	Position	Relief	Type de sol
Fragment N°01	1W	Versant	Relief de dissection	sol jaune brun sur rouge jaunâtre (ultisol)
	1E	Sommet	Relief de dissection	Sol typique à structure polyédrique (oxisol)
	1NMV	Bas-versant	Colline disséquée	sol jaune sur rouge jaunâtre (ultisol)
	1NSO	Sommet	Relief de dissection	Sol typique à structure polyédrique (oxisol)
	1MV	Bas-versant	Relief convexe	sol ferrallitique rajeuni (ultisol)
Fragment N°02	2SO	Sommet	Relief convexe	Sol typique à structure polyédrique (oxisol)
	2EMV	Versant	Relief convexe	sol jaune brun sur rouge (ultisol)
	2NMV	Versant t	Relief convexe	sol jaune brun sur rouge jaunâtre (ultisol)
	2SSO	Sommet	Colline disséquée	Sol typique à structure polyédrique (oxisol)
	2SMV	Versant	Relief de dissection	sol jaune brun sur rouge jaunâtre (ultisol)
Fragment N°03	3N	Sommet	Colline disséquée	Sol typique à structure polyédrique (oxisol)
	3MV	Versant	Relief de dissection	sol jaune brun sur rouge jaunâtre (ultisol)
	3EMV	Bas-versant	Relief de dissection	Sol typique à structure polyédrique (oxisol)
	3SOC	Sommet	Relief convexe	Sol typique à structure polyédrique (oxisol)
	3MV	Versant	Relief de dissection	sol jaune brun sur rouge jaunâtre (ultisol)
Fragment N°04	4	Versant	Relief de dissection	Sol jaune brun sur rouge jaunâtre (ultisol)
	4EMV	Versant	Relief de dissection	sol jaune brun sur rouge jaunâtre (ultisol)
	4SOC	Sommet	Relief disséqué	Sol typique à structure polyédrique (oxisol)
	4WMV	Bas-versant	Relief de dissection	Sol typique à structure polyédrique (oxisol)
	4SO	Sommet	Relief disséqué	Sol typique à structure polyédrique (oxisol)
Fragment N°05	5SO	Sommet	Relief disséqué	Sol typique à structure polyédrique (oxisol)
	5BV	Bas-versant	Relief de dissection	Sol typique à structure polyédrique (oxisol)

Tableau 1 Tableau Recapitulatif De Types De Sols (suite)

Site	Fosse	Position	Relief	Type de sol
	5MV	Versant	Relief de dissection	Sol jaune brun sur rouge jaunâtre (ultisol)
Fragment N°06	6MV	Versant	Relief de dissection	Sol jaune brun sur rouge jaunâtre (ultisol)
	6SO	Sommet	Relief de dissection	Sol typique à structure polyédrique (oxisol)
Fragment N°07	7	Bas-fonds	Relief convexe	Sol hydromorphe organique (histosol)
	7SMV	Bas-versant	Relief convexe	Sol ferrallitique rajeuni (<i>ultisol</i>)
	7MV	Versant	Relief convexe	Sol jaune brun sur rouge jaunâtre (ultisol)
	7EMV	Versant	Relief de dissection	Sol jaune brun sur rouge jaunâtre (ultisol)
	7N	Versant	Relief de dissection	Sol jaune brun sur rouge jaunâtre (ultisol)
Fragment N°08	8E	Versant	Relief de dissection	Sol jaune brun sur rouge jaunâtre (ultisol)
	8N	Versant	Relief de dissection	Sol jaune brun sur rouge jaunâtre (ultisol)
	8SO	Sommet	Relief disséqué	Sol typique à structure polyédrique (oxisol)
	8W	Versant	Relief de dissection	Sol jaune brun sur rouge jaunâtre (ultisol)
Fragment N°09	9SO	Sommet	Relief disséqué	Sol typique à structure polyédrique (oxisol)
	9MV	Versant	Relief disséqué	Sol jaune brun sur rouge jaunâtre (ultisol)
	9N	Versant	Relief disséqué	Sol jaune sur rouge à évoluée (ultisol)
	9E	Versant	Relief de dissection	Sol jaune brun sur rouge jaunâtre (ultisol)
	9S	Versant	Relief de dissection	Sol jaune brun sur rouge jaunâtre (ultisol)
Fragment N°10	10SO	sommet	Relief disséqué	Sol typique à structure polyédrique (oxisol)
	10SBV	Bas-versant	Relief convexe	Sol ferrallitique rajeuni (ultisol)
	10ESO	Sommet	Relief de dissection	Sol peu évolué (<i>entisol</i>)
	10BF	Bas-versant	Relief de dissection	Sol typique à structure polyédrique (oxisol)
Fragment N°11	11	Versant	Relief de dissection	Sol jaune brun sur rouge jaunâtre (ultisol)

Tableau 1 Tableau Recapitulatif De Types De Sols (suite)

Site	Fosse	Position	Relief	Type de sol
	11NMV	Versant	Relief de dissection	Sol ferrallitique jaune (ultisol)
	11SO	sommet	Relief disséqué	Sol typique à structure polyédrique (oxisol)
	11SBV	Bas-versant	Relief convexe	Sol ferrallitique rajeuni (<i>ultisol</i>)
	11W	Versant	Relief de dissection	Sol jaune brun sur rouge jaunâtre (ultisol)
Fragment N°12	12WMV	Versant	Relief de dissection	Sol jaune brun sur rouge jaunâtre (ultisol)
	12SO	Sommet	Relief convexe	Sol typique à structure polyédrique (oxisol)
	12S	Bas-versant	Relief de dissection	Sol typique à structure polyédrique (entisol)
Fragment N°13	13EMV	Versant	Relief de dissection	Sol jaune brun sur rouge jaunâtre (ultisol)
	13SO	Sommet	Relief convexe	Sol typique à structure polyédrique (oxisol)
	13N	Versant	Relief de dissection	Sol ferrallitique jaune brun (ultisol)
	13S	Bas-versant	Relief convexe	Sol jaune sur rouge à rajeuni (ultisol)
	13W	Versant	Relief de dissection	Sol typique à structure polyédrique (oxisol)
Fragment N°14	14N	Bas-versant	Relief de dissection	Sol typique à structure polyédrique (oxisol)
	14E	Versant	Relief de dissection	Sol jaune sur rouge jaunâtre (ultisol)
	14S	Versant	Relief de dissection	Sol jaune brun sur rouge (ultisol)
	14SO	Sommet	Relief disséqué	Sol typique à structure polyédrique (oxisol)
Fragment N°15	15E	Versant	Relief de dissection	Sol jaune brun sur rouge jaunâtre (ultisol)
	15N	Versant	Relief de dissection	Sol jaune brun sur rouge jaunâtre (ultisol)
	15S	Bas-versant	Relief de dissection	Sol typique à structure polyédrique (oxisol)
	15W	Versant	Relief résiduel	Sol typique à structure polyédrique (oxisol)
	15SO	Sommet	Relief résiduel	Sol typique à tendance évoluée (<i>oxisol</i>)
Transect Akondro-morona	1b	Sommet	Relief de dissection	Sol peu évolué d'érosion (<i>entisol</i>)
	2b	Versant	Relief de dissection	Sol peu évolué d'érosion avec concrétions (<i>entisol</i>)

Tableau 1 Tableau Recapitulatif De Types De Sols (suite)

Site	Fosse	Position	Relief	Type de sol
	3b	Versant	Relief de dissection	Sol ferrallitique jaune brun avec concrétions (ultisol)
	4b	Versant	Relief de dissection	Sol ferrallitique jaune brun (ultisol)
	5b	Bas-versant	Relief de dissection	Sol jaune typique à structure polyédrique (oxisol)
	6b	Versant	Relief convexe	Sol ferrallitique jaune brun sur rouge avec concrétions (oxisol)
	7b	Versant	Relief de dissection	Sol ferrallitique jaune brun sur rouge avec concrétions (oxisol)
	8b	Versant	Relief résiduel	Sol ferrallitique jaune brun sur rouge (oxisol)
	9b	Versant	Relief de dissection	Sol peu évolué d'érosion jaune brun sur rouge avec de stone-lines(entisol)
	10b	Versant	Relief de dissection	Sol peu évolué d'érosion jaune brun sur rouge (ultisol)
	11b	Sommet	Relief convexe	Sol typique à structure polyédrique (oxisol)
Transect Ambohi-manarivo	1	Bas-versant	Relief de dissection	Sol typique à structure polyédrique (oxisol)
	2	Versant	Relief de dissection	sol jaune brun sur rouge micacé et concrétionné de quartz (ultisol)
	3	Versant	Relief de dissection	sol jaune brun sur rouge micacé et concrétionné de quartz (oxisol)
	4	Sommet	Relief de dissection	Sol peu évolué d'érosion jaune sur rouge concrétionné (oxisol)
	5	Bas-versant	Relief de dissection	Sol jaune brun sur rouge (ultisol)
	6	Sommet	Relief de dissection	Sol jaune brun sur rouge micacé et concrétionné (ultisol)
	7	Bas-versant	Relief disséqué	Sol typique à structure polyédrique avec des concrétions et blocs (remaniement)(ultisol/ oxisol)
	8	Versant	Relief de dissection	Sol jaune brun sur rouge micacé et concrétionné (ultisol)
	9	Versant	Relief de dissection	Sol typique à structure polyédrique (oxisol)
	10	Versant	Relief de dissection	Sol jaune brun sur rouge micacé et concrétionné (ultisol)
	11	Sommet	Relief convexe	Sol typique à structure polyédrique micacé et concrétionné (oxisol)




PIPELINE SOIL SURVEY PHOTOS

4 FRAGMENTS DE FORÊT




4.1 RELIEF DE DISSECTION OU RESIDUEL

<i>Au sommet</i>	<i>Au versant</i>	<i>Au bas- versant</i>
		
<p><i>sol caractéristique de sommet de relief de dissection de type peu évolué jaune brun sur rouge jaunâtre (horizon AC) avec quelques concrétions. (soil taxonomy entisol)</i></p>	<p><i>sol caractéristique de versant de relief de dissection de type jaune brun sur rouge jaunâtre avec faibles concrétions. (soil taxonomy : ultisol)</i></p>	<p><i>sol caractéristique de bas-versant de relief de dissection de type ferrallitique typique à structure polyédrique. (soil taxonomy : oxisol)</i></p>




4.2 COLLINES OU CROUPES DISSÉQUÉES

<i>Au sommet</i>	<i>Au versant</i>	<i>Au bas- versant</i>
		
<p><i>Sols ferrallitiques typiques à structure polyédrique (oxisols)</i></p>	<p><i>Sols ferrallitiques fortement rajeunis ou pénévulés (ultisols)</i></p>	<p><i>Sols peu évolués humifère (d'érosion et/ou d'apport) (ultisols/entisols)</i></p>

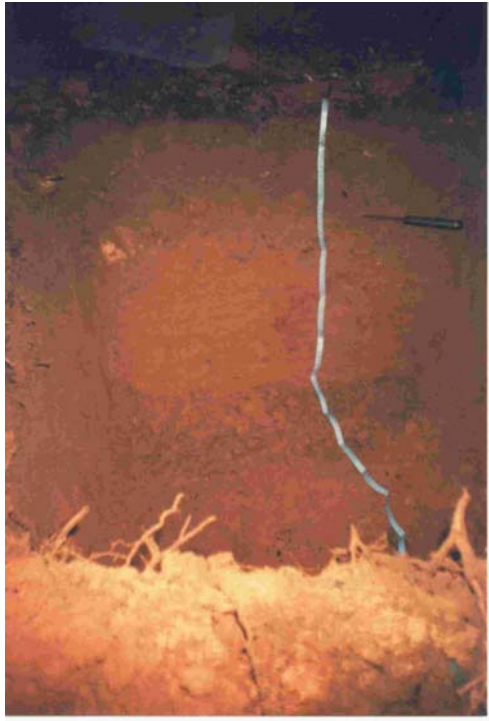


4.3 COLLINES OU CROUPES CONVEXES

<i>Au sommet</i>	<i>Au versant</i>	<i>Au bas- versant</i>
		
Sols ferrallitiques typiques à structure polyédrique (oxisols)	Sols ferrallitiques rajeunis (ultisols)	Sols fortement rajeunis ou pénévlués (ultisols)

5 TRANSECT AKONDROMORONA

<i>Au sommet</i>	<i>Au versant</i>	<i>Au bas- versant</i>
		
<i>sol caractéristique de sommet de relief de dissection de type ferrallitique à structure polyédrique micacé et présence de faible concrétions. (soil taxonomy oxisol)</i>	<i>sol caractéristique de versant de collines ou croupes convexes de type jaune brun sur rouge jaunâtre avec faibles concrétions. (soil taxonomy : ultisol)</i>	<i>sol caractéristique de bas-versant de relief disséqué de type ferrallitique typique à structure polyédrique. (soil taxonomy : oxisol)</i>

6 TRANSECT AMBOHIMANARIVO

<i>Au sommet</i>	<i>Au versant</i>	<i>Au bas- versant</i>
		
<p><i>sol caractéristique de sommet de relief de dissection de type peu évolué jaune brun sur rouge jaunâtre (horizon AC) micacé avec quelques concrétions. (soil taxonomy entisol)</i></p>	<p><i>sol caractéristique de versant de relief de dissection de type jaune brun sur rouge jaunâtre fortement micacé et avec faibles concrétions. (soil taxonomy : ultisol)</i></p>	<p><i>sol caractéristique de bas-versant de relief de dissection de type ferrallitique typique à structure polyédrique micacé et présence de stone-lines. (soil taxonomy : oxisol)</i></p>

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APPENDIX 3.1

ATTACHMENT 4

**TABLEAU DES RESULTATS D'ANALYSES PHYSICO-CHIMIQUES DES
ECHANTILLONS DES SOLS**

Tableau 1 Tableau Des Resultats D’analyses Physico-Chimiques Des Echantillons Des Sols

Sigle	pH (eau)	pH KCl	N(%)	P(ppm)	C(%)	MO (%)	C/N (%)	Acidité d'échange (meq/100g)			Bases échangeables (meq/100g)				Somme des bases	CEC (meq/100g)	Granulométrie (%)				Taux de saturation (%)
								Al3++H+	Al3+	H+	Ca	Mg	Na	K			Argile	Limon	Sable	Texture	
15SO MO	5.12	4.89	0.217	4.1	3.66	6.29	16.8	1.99	1.92	0.07	0.132	0.691	0.1	0.079	1.002	11.1	20	18	62	Limono-sableux	9.02
7 MO	5.02	4.9	0.273	0.9	4.52	7.77	16.5	2.37	2.18	0.19	0.222	0.325	0.152	0.12	0.819	15.5	26	32	42	Limoneux	5.28
1b MO	5.05	4.8	0.042	3	0.189	0.325	4.5	0.108	0.104	0.004	0.06	0.018	0.065	0.013	0.156	5.2	18	38	44	Limoneux	3
12SO MO	5.55	4.83	0.161	4.3	2.69	4.62	16.7	1.99	1.77	0.22	0.088	0.095	0.104	0.054	0.341	7.9	16	18	66	Limono-sableux	4.31
14MV MO	5.64	5.2	0.126	0.3	1.91	0.028	15.1	0.378	0.364	0.014	0.034	0.108	0.078	0.038	0.258	6.4	18	12	70	Limono-sableux	3.98
7SO MO	5.08	4.98	0.189	1.7	3.03	5.21	15	0.756	0.728	0.028	0.065	0.158	0.221	0.049	0.493	6.3	28	16	56	Limono-argilo-sableux	7.82
3b MO	5.25	5	0.168	1.9	2.78	4.78	16.5	1.62	1.56	0.06	0.142	0.258	0.1	0.089	0.589	9.2	22	18	60	Limono-argilo-sableux	6.4
1MV MO	5.14	4.77	0.252	2.4	2.68	4.6	10.6	1.78	1.3	0.48	0.555	0.308	0.121	0.126	1.11	7.8	22	26	52	Limono-argilo-sableux	14.23
9SO2 MO	4.4	4	0.84	11.9	21.6	37.1	25.7	11.3	8.63	2.67	0.094	0.608	0.421	0.461	1.584	66.6	15	30	55	Limono-sableux	2.37
5SO MO	5.21	4.93	0.322	1.9	3.22	5.53	10	1.94	1.66	0.28	0.209	0.241	0.213	0.238	0.901	12	38	30	32	Limono-argileux	7.5
3SO MO	5	4.9	0.098	1.6	0.856	1.47	8.7	1.73	1.71	0.02	0.059	0.333	0.208	0.307	0.907	5.9	18	24	58	Limono-sableux	15.37
1S MO	5.13	4.95	0.24	4.4	3.68	6.32	15.3	1.99	1.82	0.17	0.162	1.16	0.165	0.171	1.658	13.8	24	26	50	Limono-argilo-sableux	12.01
1SON H1	4.66	4.51		5				1.29	1.29	0	0.039	0.133	0.108	0.031	0.311	5.9	36	18	46	Limono-argileux	5.27
14MV H1	4.88	4.73		0.8				0.162	0.162	0	0.059	0.125	0.265	0.02	0.469	3.9	24	18	58	Limono-argilo-sableux	12.02
1b H1	4.51	4.4		14				1.75	1.35	0.4	0.082	0.45	0.121	0.146	0.799	13.7	28	36	36	Limono-argileux	5.83
13MV H1	4.47	4.35		1.1				1.35	1.19	0.16	0.056	0.1	0.086	0.049	0.291	6.3	30	26	44	Limono-argilo-sableux	4.62
2MV H1	4.93	4.78		1.3				0.594	0.572	0.022	0.091	0.1	0.113	0.033	0.337	3.8	26	18	56	Limono-argileux	8.86
7H1	4.61	4.48		1				0.756	0.754	0.002	0.072	0.35	0.091	0.038	0.551	5	46	28	26	Argileux	11.02
10b H1	4.48	4.35		2.3				2.04	1.78	0.26	0.058	0.15	0.135	0.069	0.412	7.3	26	26	48	Limono-argilo-sableux	5.64
4EMV H1	4.49	4.39		3.1				2.95	2.7	0.25	0.087	0.25	0.1	0.048	0.485	6.9	40	24	36	Limono-argileux	7.02
6MV H1	4.82	4.73		3.6				0.918	0.918	0	0.064	0.108	0.139	0.056	0.367	4.6	24	16	60	Limono-argilo-sableux	7.97
1S H1	4.78	4.47		1.8				1.98	1.78	0.2	0.076	0.366	0.152	0.066	0.66	6.1	24	26	50	Limono-argilo-sableux	10.82
3b H1	4.86	4.79		1.3				0.459	0.459	0	0.085	0.116	0.104	0.033	0.338	5.2	38	14	48	Argilo-sableux	7.13
Site8C H1	4.6	4.51		3.8				1.78	1.63	0.15	0.086	0.25	0.1	0.064	0.5	8.5	18	24	58	Limono-sableux	5.88
10b H2																	32	26	42	Limono-argileux	
Site8C H2																	30	22	48	Limono-argilo-sableux	
1S H2																	24	28	48	Limono-sableux	

Source : FOFIFA Laboratoire de pédologie Antananarivo (Tsimbazaza)

VOLUME I

APPENDIX 3.1

ATTACHMENT 5

**TABLEAU DE CORRESPONDANCE DE CLASSIFICATION CPCS ET
TAXONOMY DES SOLS SELON LEUR TYPOLOGIE**

Tableau De Correspondance De Classification Cpcs Et Soil Taxonomy Des Sols Selon Leur Typologie

Classification française CPCS 1967	Soil Taxonomy (Classification américaine) Groupes principaux
Sol peu évolué humifère	Lithic haplumbrepts (Entisol)
Sol ferrallitique fortement désaturé humique	Typique Acrohumox (Oxisol)
Sol ferrallitique fortement désaturé typique jaune	Typic haplorthox (Oxisol)
Sol ferrallitique fortement désaturé typique rouge	Rhodic haplusthox (Oxisol)
Sol ferrallitique fortement désaturé remanié	Oxic Dystropepts (Oxisol)
Sol ferrallitique fortement désaturé –rajeuni ou pénévoué	Haplorthox and Acrorthox (Ultisol)
Sol ferrallitique fortement désaturé lessivé	Typic paleudult (Ultisol)
Sol hydromorphe organique	Histosol

VOLUME I

APPENDIX 3.1

ATTACHMENT 6

AGRICULTURAL LAND SUITABILITY OF THE MINE SITE

1 AGRICULTURAL LAND SUITABILITY

1.1 INTRODUCTION

The Food and Agriculture Organization of the United Nations (FAO) uses a land suitability system based on soil suitability. Suitability is defined as the adaptability of a given area for a specific kind of land use (FAO, 1976). The FAO land suitability system uses a two-stage approach to determine land suitability:

- Stage 1 is mainly concerned with qualitative land evaluation.
- Stage 2 consists of an economic and social analysis (Stage 2 does not necessarily need to be completed).

The FAO land suitability system is a framework around which national and local systems can be constructed. The land uses are defined as closely as the purposes and soil survey intensity require. In reconnaissance surveys, this may be the major kinds of land use (Young, 1976). The system is flexible and is based on the following principles:

- Land suitability is assessed and classified with respect to specified kinds of use. The qualities of each type of land, such as moisture availability or liability to flooding, are compared with the requirements of each use. Thus the land itself and the land use are equally fundamental to land suitability evaluation.
- Evaluation requires a comparison of the benefits obtained and the inputs needed on different types of land. Suitability for each use is assessed by comparing the required input, such as labour, fertilizers or road construction, with the goods produced or other benefits obtained.
- A multidisciplinary approach is required. When completing quantitative evaluation the comparison of benefits and inputs in economic terms plays a major part in determining suitability.
- Agricultural suitability ratings are made in terms relevant to the physical, economic and social context of the area concerned.
- Suitability refers to use on a sustained basis and environmental degradation is considered when assessing suitability.
- Suitability evaluation involves comparison of more than a one kind of land use. Evaluation is only reliable if benefits and inputs from any given kind of use can be compared with at least one, and usually several different, alternatives. (FAO, 1976).

The FAO land suitability system is hierarchal in structure (Figure 1). The four levels in the hierarchy of land suitability categories are land suitability order, land suitability classes, land suitability subclasses and land suitability units (Table 1).

Figure 1 Structure of the Food and Agriculture Organization of the United Nations Land Suitability Classification

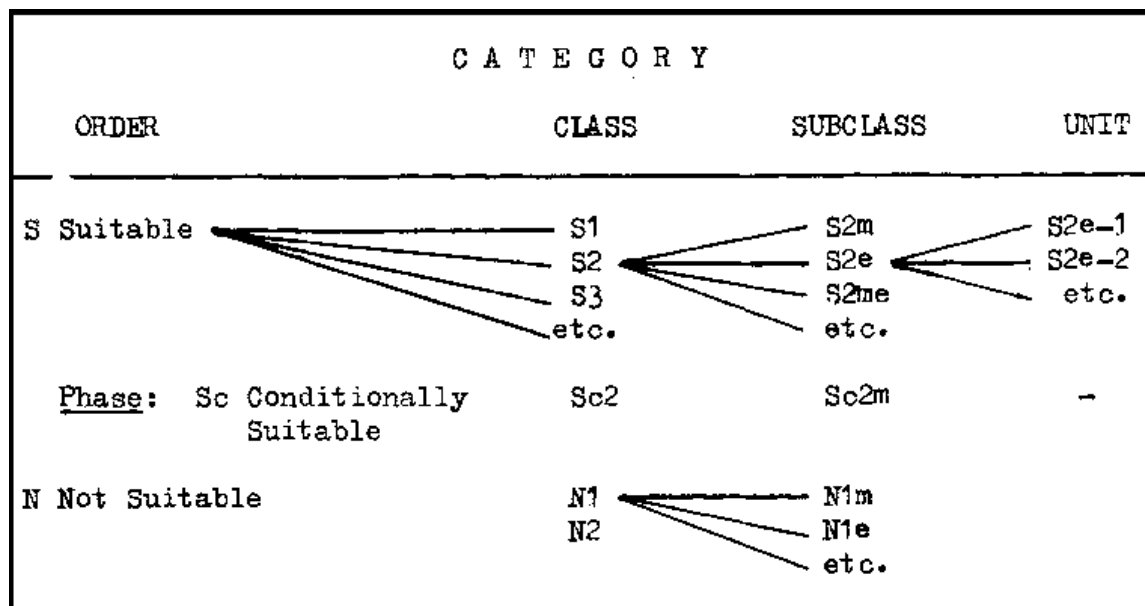


Table 1 Food and Agriculture Organization of the United Nations Land Suitability Categories

i. Land Suitability Orders:	reflecting kinds of suitability
ii. Land Suitability Classes:	reflecting degrees of suitability within Orders
iii. Land Suitability Subclasses:	reflecting kinds of limitation, or main kinds of improvement measures required, within Classes
iv. Land Suitability Units:	reflecting minor differences in required management within Subclasses

1.2 LAND SUITABILITY ORDERS

Land suitability is classified into two orders: Suitable (S) and Not Suitable (N). Suitable land is defined as “land on which sustained use of the kind under consideration is expected to yield benefits which justify the inputs, without unacceptable risk of damage to land resources”. Non Suitable land is defined as “land which has qualities that appear to preclude sustained use of the kind under

consideration". Land may be classed as Not Suitable for a given use for a number of reasons such as the risk of severe environmental degradation (i.e. cultivation of steep slopes) or because the economic value of the expected benefits does not justify the expected costs of the inputs that would be required. (FAO 1976).

1.2.1 Land Suitability Classes

There are several land suitability classes for both Suitable (S) and Non Suitable (N) orders. Suitability classes for Suitable (S) land reflect the degrees of suitability. Generally three land suitability classes are used (Table 2).

Table 2 Common Food and Agriculture Organization of the United Nations Land Suitability Classes for the Suitable Land Orders

Class S1 Highly Suitable:	land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level
Class S2 Moderately Suitable:	land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on Class S1 land
Class S3 Marginally Suitable:	land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified

There are two land suitability classes for Non Suitable Land (Table 3).

Table 3 Non Suitable Land Classes

Class N1 Currently Not Suitable:	land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost; the limitations are so severe as to preclude successful sustained use of the land in the given manner
Class N2 Permanently Not Suitable:	land having limitations which appear so severe as to preclude any possibilities of successful sustained use of the land in the given manner

1.3 LAND SUITABILITY SUBCLASSES

Land suitability subclasses reflect kinds of limitations (i.e. moisture deficiency, erosion hazard) for suitable (S) land. Subclasses are designated by lower-case letters and the number of subclasses distinguishes lands within a class likely to

differ significantly in their management requirements or potential for improvement due to differing limitations.

Land within the Not Suitable Order (N) may be divided into suitability subclasses according to kinds of limitation but this is not usually done since land will not be managed for agriculture.

1.4 LAND SUITABILITY UNITS

Land suitability units are subdivisions of a subclass that differ from each other in their production characteristics or in minor aspects of their management requirement. There is no limit to the number of units recognized within a subclass.

1.4.1 Conditional Suitability

Conditionally Suitable (CS) is a phase of Suitable Land Order (S) that defines when land is suitable provided that certain conditions are fulfilled. In the FAO land suitability system the Conditionally Suitable (CS) phase is avoided wherever possible. It is only used when:

- the land is either not suitable or belongs to the lowest suitable class unless the specified condition(s) are in place;
- the Conditional Suitability should be at least two classes higher than equivalent suitability class; and / or
- the extent of the conditionally suitable land is very small with respect to the total study area.

The land suitability subclasses are described below:

Topography - (land suitability subclass - t) Slope effects agricultural land suitability because of the increase potential for water erosion and decreasing the uniformity of growth of crops.

Erosion - (land suitability subclass - e) Erosion effects agricultural land suitability because of the loss in soil nutrients, organic matter, productivity and the difficulty in farming on land with rills and gullies.

Rooting Depth - (land suitability subclass - r) Soil with an impediment or barrier to root growth effects agricultural land suitability because the ability of plants to exploit soil water and nutrients.

Soil acidity (land suitability subclass - a) Low soil pH have several effects on agricultural land suitability. Mineral deficiencies and aluminum toxicity increase at low soil pH. Soil microbial activity at lower pH values tend to convert organic minerals to soluble inorganic forms. Soils with a pH less than 5.0 are considered strongly acidic. Below this value aluminum (Al^{3+}) ions progressively replace hydrogen (H^+) ions and aluminum toxicity can become a problem (Young, 1989). High levels of Aluminum (Al^{3+}) and Manganese (Mn^{2+}) at low pH may be toxic to some crops, have an adverse effect on root growth, cause phosphorus to become immobile and unavailable to plants and effects the translocation of nutrients. Fixation of phosphorus is also most serious when soil pH is below 5.0 (Buckman and Brady, 1974).

Low Fertility - (land suitability subclass - f) Nutrients – Low fertility effects agricultural land suitability since there are low nutrient levels for plant growth and a limited capacity for holding nutrient additions or reserves. A common measure of soil fertility is cation exchange capacity (CEC). Soils with low CEC are generally low in nutrients and are highly limited in retaining nutrient reserves.

Nickel, cobalt and chromium toxicity (land suitability subclass - n) High levels of nickel, cobalt and chromium in soils effects agricultural land suitability because they are reported to be phytotoxic (Whitmore, 1975).

Soil Organic Matter - (land suitability subclass - o) Low levels of soil organic matter effects agricultural land suitability because the nutrient availability of phosphorus, nitrogen and carbon diminishes with decrease in organic matter. Soil organic matter limitation is closely related to the fertility limitation.

Soil Wetness (land suitability subclass - w) Soil wetness affects agriculture land suitability because of rooting depth, soil physical properties, nutrient availability and soil aeration.

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VOLUME I: PHYSICAL APPENDICES

APPENDIX 3.2: SOILS EA APPENDIX

USING VETIVER FOR EROSION CONTROL

Submitted to:

Dynatec Corporation

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3.2 USING VETIVER FOR EROSION CONTROL

Vetiver (*Vetiveria zizanioides*) is a native grass from India that is being used throughout the tropics for erosion control (NRC 1993). It has been used in Madagascar for erosion control by farmers and industry for over a decade and is also suggested for erosion control of mine dumps in the country (Grimshaw 1997). Users in the tropics for erosion control have reported that planting Vetiver hedgerows will reduce soil loss up to 90% and water runoff up to 60% (Grimshaw 1997).

The National Research Council (NRC) (1993) has suggested that Vetiver has the following unique traits:

- controls erosion when planted in a hedge across the slope just one plant wide;
- certain types bear infertile seed ensuring it does not encroach and spread;
- the plants are hardy and have been documented to survive drought, grazing, fire and floods. They are not tolerant to freezing;
- they are deep-rooted plants with roots having a high tensile strength allowing them to hold the soil against erosion;
- inexpensive to establish and require low maintenance; and
- grow in diverse soil types including saline, acid and low fertility.

For this project, trials of Vetiver are proposed for the initial waste dumps that are established to evaluate the potential of this species for the overall mining program.

4 REFERENCES

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VOLUME I: PHYSICAL APPENDICES

APPENDIX 4.1

CLIMATE AND AIR QUALITY BASELINE

Submitted to:

Dynatec Corporation

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1 INTRODUCTION

A description of the regional climate (i.e., long-term weather conditions), meteorology (i.e., the local variability in weather including variability in temperature, precipitation and wind) and ambient air quality are presented for the different Ambatovy Project (the project) sites in this Appendix. Additional analyses of climate data, with emphasis on parameters of relevance to hydrology, are provided in Volume I, Appendix 8.1.

2 METHODS

The methods for describing the climate included completing a literature review of previous climate research in Madagascar and summarizing long-term data from stations near the different project sites, namely Moramanga for the mine site and Toamasina for the process plant, tailings facility and port expansion.

The methods required for summarizing the meteorology at the mine site included compiling all the data received from the two meteorological towers set up in November 1996 at or near the mine site. Data from the village station (along Route National 44 [RN 44]) are available from November 1996 but the station was decommissioned in November 2001. Data from the exploration camp is available from November 1996 to March 2005.

Both stations are GroWeatherTM integrated weather station and data logger installations manufactured by the Davis Instruments Corp. Each station measures temperature, dew point temperature, relative humidity, precipitation, barometric pressure, solar radiation, wind speed and wind direction. The data are continuously recorded at 10-minute intervals with some periods recorded half-hourly.

Meteorology at the process plant, tailings facility and port expansion sites was described using hourly meteorological data from the Toamasina station, located at the Ambalamanasy Airport. Data were obtained through the National Climatic Data Center (NCDC) which is a division of the U.S. National Oceanic and Atmospheric Administration (NOAA).

Analysis of current ambient air quality at the project sites included a literature review of air quality monitoring performed in Madagascar and/or other similar locations.

3 RESULTS

3.1 GENERAL RESULTS

Madagascar has a very diverse climate primarily due to the range of latitudes that it spans and the ridge of mountains which lies along the east side of the island. The island lies off the southeast coast of Africa and extends 1,650 km in the north-south from 12° to 25° S. The northern part of the island experiences a tropical climate while the south experiences a more subtropical climate. The mountain ridge running north-south along the eastern edge of the island has a significant affect on the climate of the island. The ridge has an average elevation of 1,200 m with massifs reaching above 2,600 m.

There are two seasons in most of Madagascar. The cooler, dry season occurs from May through September and the warm, rainy season occurs from November through March with transition periods typically during October and April. The northern part of the island is typically warmer and more humid than the southern part. Average annual temperatures range between 26 and 29°C in the north and between 20 and 27°C in the southwest. Rainfall varies significantly on the island with the southern tip receiving less than 400 mm of rain per year while northern locations receive more than 3,000 mm per year.

The east coast receives regular rainfall throughout the year due to the predominant easterly and southeasterly winds being lifted by the mountain ridge. Annual rainfall amounts of more than 3,000 mm are common along the east coast and can exceed 5,000 mm at higher elevations in the north.

During the summer, the island is frequently impacted by tropical cyclones. On average, 10 tropical cyclones per year make landfall from December to March. Based on 40 years of observations, about 70% of all tropical cyclones occur from January 15 to March 15 (Jury 2003). Wind speeds can reach over 200 km/hr during these cyclones. Except for the east coast, most of the island is influenced by dry trade wind conditions during the winter months resulting in little rainfall.

There is little information available regarding ambient air quality in Madagascar; however, rural areas, such as the mine site and tailings facility, are expected to have very good air quality due to the lack of industrial activities. Fires, road dust and agricultural activities may have an impact on air quality in rural areas. In urban centres, such as Toamasina, air quality is affected by existing vehicle traffic and industrial activities.

3.2 MINE SITE

3.2.1 Climate

The mine site is located 15 km north-northeast of Moramanga on one of two escarpments that separate the central plateau from the east coast. The area experiences distinct wet and dry seasons with about 80% of the rainfall occurring from November through March. The average annual rainfall at Moramanga is 1,468 mm. Daily average temperatures at Moramanga range from 16°C during the dry season to 22°C during the wet season with an annual average of 20°C. A more detailed analysis of the rainfall at the mine site is presented in the Hydrology Baseline (Volume I, Appendix 8.1).

3.2.2 Meteorology

Two meteorological towers were installed at the mine site in 1996. One station was installed at a lower elevation along RN 44 west of the mine site and was decommissioned in 2001. The other station is still in operation at the exploration camp site on top of the ridge at the Ambatovy ore body.

3.2.2.1 Temperature, Precipitation and Relative Humidity

Based on data from 1997 to 2004, hourly temperatures at the exploration camp station ranged from 7.6°C in August 2003 to 31.1°C in February 1997 with an annual average temperature of 17°C. The exploration camp is about 1.5°C cooler than the RN 44 station because of its higher elevation. The average annual temperature at the RN 44 station, based on data from 1997 to 2001, was 18.5°C.

Annual average rainfall at the mine site was about 1,400 mm with almost 70% occurring from December to March. The RN 44 station received 963 mm of rain in 1997 (rainfall data from 1998 to 2001 were incomplete).

The annual relative average humidity at the exploration camp was 95% with minimum values between 30 and 40%. The average relative humidity at the RN 44 station was about 90% with minimum values around 25%.

3.2.2.2 Wind Speed and Direction

Figure 4.1-1 shows a windrose of data collected at the exploration camp from 1997 to 2004. The windrose consists of bars whose length indicates the frequency of winds blowing from a given direction. The bars are also broken into sections, each of which defines a speed range. A longer section indicates

that winds blow more frequently at a given speed for that direction. East-southeast and southeast winds were predominant and occur 59% of the time excluding calms. The average annual wind speed was 6 km/hr with maximum hourly speeds of up to 48 km/hr and gust speeds over 80 km/hr. There was also a high frequency of calm conditions (14.2%).

Figure 4.1-1 Mine Site Exploration Camp Windrose (1997 to 2004)

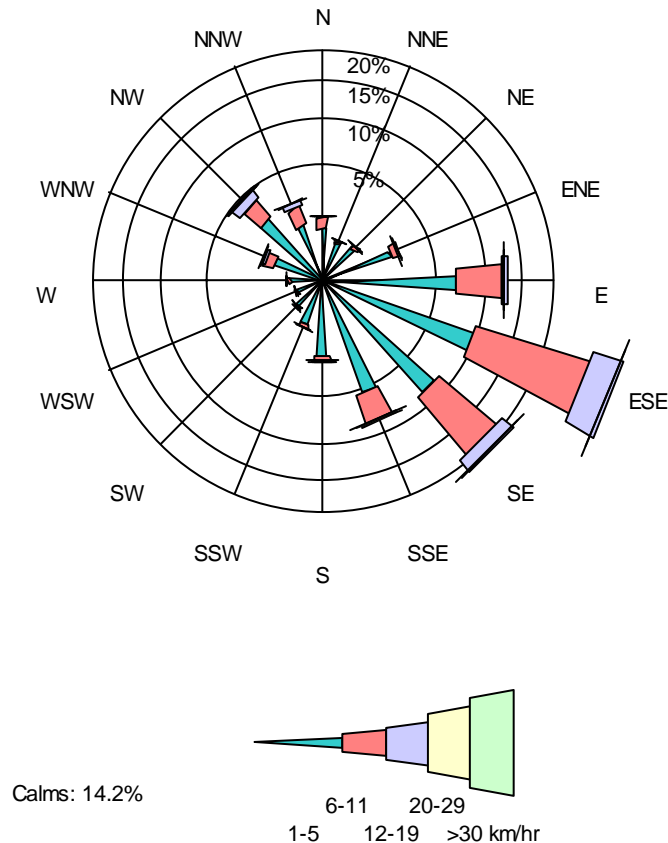
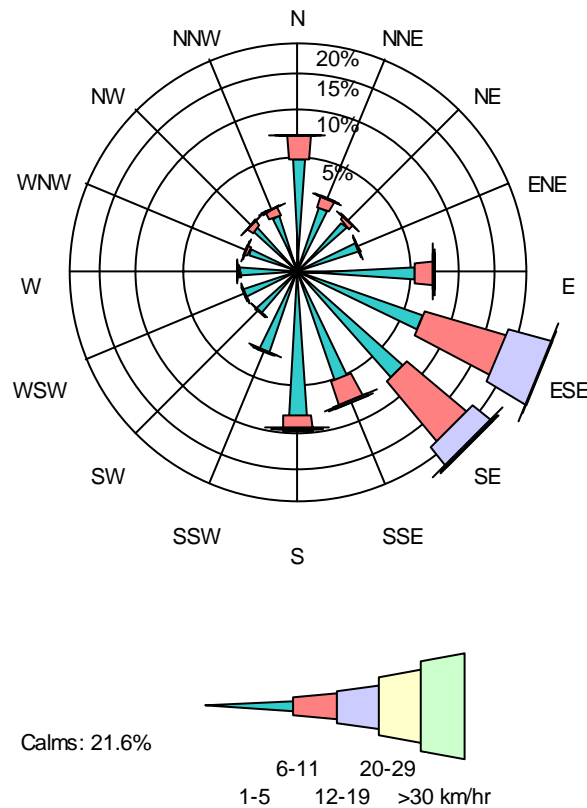


Figure 4.1-2 shows a windrose for the RN 44 station based on 1997 data, which was the most complete year of data. East-southeast and southeast winds are predominant and occur 50% of the time excluding calms, which is similar to the exploration camp site. There was a higher frequency of north and south winds which may have been the result of channelling in the river valley. The average wind speed was 5 km/hr with maximum gusts up to 72 km/hr. There was also a higher frequency of calm conditions than at the exploration camp (21.6% of the time).

Figure 4.1-2 Route National 44 (RN 44) Station Windrose (1997)



3.2.2.3 Atmospheric Stability

Atmospheric stability is an indirect measure of atmospheric turbulence. The amount of atmospheric turbulence determines how quickly emissions are dispersed and mixed as they are transported by the wind. Turbulence can be generated by either mechanical or thermal mechanisms. Surface heating or cooling by solar radiation contributes to the generation or suppression of thermal turbulence, while high wind speeds contribute to the generation of mechanical turbulence.

One generalized scheme to classify atmospheric stability was developed by Pasquill and Gifford (Pasquill 1961) (referred to as Pasquill-Gifford, or PG, stability classes). The classification scheme comprises six categories: Classes A, B and C (Unstable); Class D (Neutral); and Classes E and F (Stable). These stability classes are used in air dispersion modelling, in conjunction with other meteorological parameters, to determine how air emissions are dispersed. A description of these categories is provided below:

- Unstable conditions are primarily associated with daytime heating conditions, which result in enhanced turbulence levels (i.e., convection) and enhanced dispersion of airborne emissions.
- Neutral conditions are associated with moderate to high wind speeds or overcast conditions, which temper the amount of radiation cooling and heating. Dispersion under neutral conditions is affected more by mechanical turbulence (wind speed) than by surface heating or cooling.
- Stable conditions often occur as a result of nighttime cooling. This results in suppressed turbulence levels and weaker dispersion of airborne emissions.

The preferred method of calculating PG stability classes is the Turner method (Turner 1964); however, this method requires cloud cover and ceiling height data which is not available at the mine site. Therefore, a modified version of the solar radiation/delta-T (SRDT) method from the U.S. Environmental Protection Agency (U.S. EPA) was used to calculate stability classes (U.S. EPA 2000). This method uses wind speed and solar radiation measured at the exploration camp station. The relationship between the PG stability classes, solar radiation and wind speed during the day is given in Table 4.1-1. At night, if the wind speed was greater than or equal to 2.5 m/s then the stability class was set to D. If nighttime wind speeds were less than 2.5 m/s, the stability class was set to F. The PG stability classes were calculated for the exploration camp but not for the RN44 site. The exploration camp data are more representative of the mine site and more appropriate for use in mine site air dispersion modeling.

Table 4.1-1 Key to Solar Radiation Delta-T (SRDT) Method for Estimating Pasquill-Gifford Stability Categories (Daytime)

Wind Speed [m/s]	Solar Radiation [W/m ²]			
	≥ 925	925-675	675-175	< 175
< 2	A	A	B	D
2-3	A	B	C	D
3-5	B	B	C	D
5-6	C	C	D	D
≥ 6	C	D	D	D

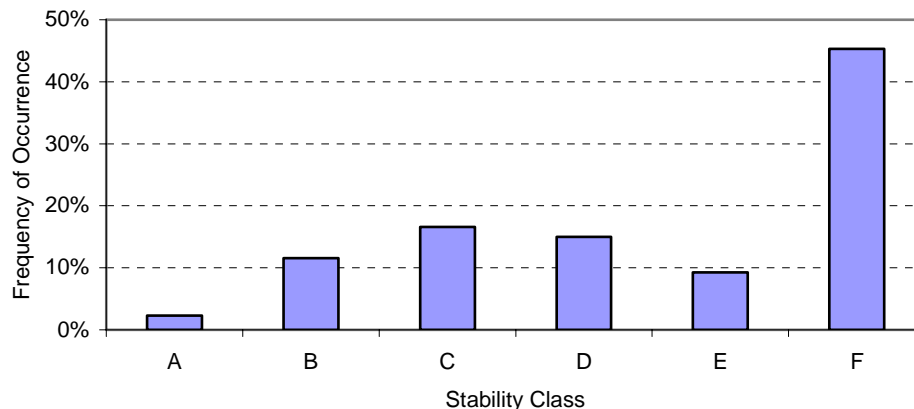
Source: U.S. EPA 2000.

W/m² = watts per square metre.

Figure 4.1-3 provides a histogram showing the frequency of the derived PG stability classes. Stability classes were calculated for the two years which had the most complete data (1997 and 2002). During these years of observed meteorological data, unstable conditions occurred about 30% of the time, neutral

conditions occurred 15% of the time, and stable conditions accounted for the remaining 55% of the observations.

Figure 4.1-3 Frequency of Pasquill-Gifford Stability Conditions at the Mine Site (1997 and 2002)



3.2.2.4 Mixing Heights

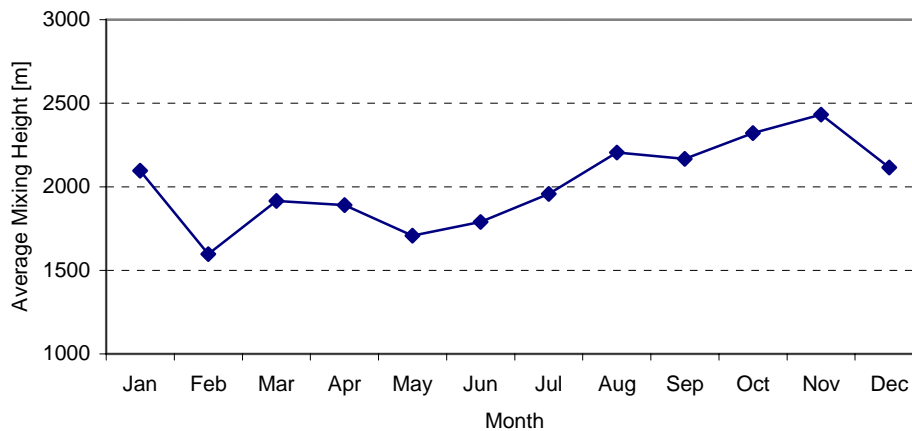
The mixing height defines the depth through which emissions released to the atmosphere are mixed through dispersive processes. The height of this layer depends on surface heating and wind turbulence. Low mixing heights can reduce dispersion and result in elevated ground level concentrations.

Ideally, mixing heights are determined from vertical profiles of wind speed and temperature and comprehensive surface data. When such data is unavailable, other methods can be used to calculate mixing heights. Since vertical profiles of winds and temperature were not available for the mine site, mixing heights were calculated from the observed surface wind speed following methods used in other jurisdictions (U.S. EPA 2000; Randerson 1984).

Figure 4.1-4 provides a monthly summary of calculated mixing heights at the mine site for the years 1997 and 2002 and for stability classes A to D. Mixing heights were set to unlimited for stable conditions (E and F). The lowest average mixing height of 1,600 m above ground occurs in February, while the highest average of about 2,400 m above ground occurs in November. These values are representative of the equatorial region where strong heating results in significant vertical mixing which can result in very large mixing heights. Dispersion of emissions from the mine site will be governed mainly by the stack height,

emission temperature and velocity since the mixing heights will likely not be reached.

Figure 4.1-4 Monthly Average Mixing Heights at the Mine Site (1997 and 2002)



3.2.3 Ambient Air Quality

A baseline ambient air quality study was not performed for this Environmental Assessment (EA); however, ambient air quality was expected to be good based on the lack of industrial activity in the region of the mine site. The exception could be airborne particles resulting from fires, road dust generated during the dry season or agricultural activities.

In a study done on the southern coast of Madagascar in August 2000, air quality was monitored at eight locations in and near Fort Dauphin. Results showed very low concentrations of sulphur dioxide (SO₂), oxides of nitrogen (NO_x), particulates as PM₁₀ (particulate less than 10 µm in diameter) and carbon monoxide (CO). All eight locations were classified as *pristine* (less than 20% of the reference standard) or *clean* (20 to 39% of the reference standard) (SENES 2001). The rural stations in this study, which were all classified as pristine, are considered representative of the ambient air quality at the mine site.

3.3 SLURRY PIPELINE

The direct pipeline route will not require a pumping station other than at the mine site. Since the pumping station will be assessed as part of the mine facilities, an air quality assessment is not required for the pipeline. Air quality effects from construction equipment is expected to be localized.

3.4 PROCESS PLANT

3.4.1 Climate

The process plant will be located 10 km southwest of the city of Toamasina on the east coast of Madagascar. Table 4.1-2 presents 30-year normals (1971 to 2000) of temperature and precipitation for Toamasina. Daily maximum temperatures at Toamasina range from 25 to 30°C during the year and daily minimum temperatures range from 17 to 23°C. Toamasina receives one of the highest rainfall amounts per year on the island (3,368 mm) with rain occurring an average of 255 days per year. A detailed analysis of precipitation at Toamasina is provided in the Hydrology Baseline (Volume I, Appendix 8.1).

Table 4.1-2 Climate Information for Toamasina (1971 to 2000)

Month	Mean Temperature [°C]		Mean Total Rainfall [mm]	Mean Number of Rain Days
	Daily Minimum	Daily Maximum		
January	22.5	30.1	410.1	23
February	22.7	30.3	382.1	20
March	22.4	29.5	478.4	24
April	21.4	28.8	322.8	21
May	19.5	27.3	228.3	22
June	17.8	25.6	259.0	21
July	17.1	24.8	288.6	25
August	17.0	24.9	218.2	24
September	17.3	25.8	121.1	19
October	18.7	26.9	132.6	18
November	20.4	28.4	169.7	17
December	21.9	29.4	357.3	21
Year	19.9	27.7	3,368.2	255

Source: WMO 2004.

3.4.2 Meteorology

The weather in the process plant site region is dominated by frequent cyclone activity and easterly trade winds. The northeastern coast of Madagascar receives regular rainfall throughout the year due to the easterly and southeasterly winds being lifted by the mountain ridge.

3.4.2.1 Temperature, Precipitation and Relative Humidity

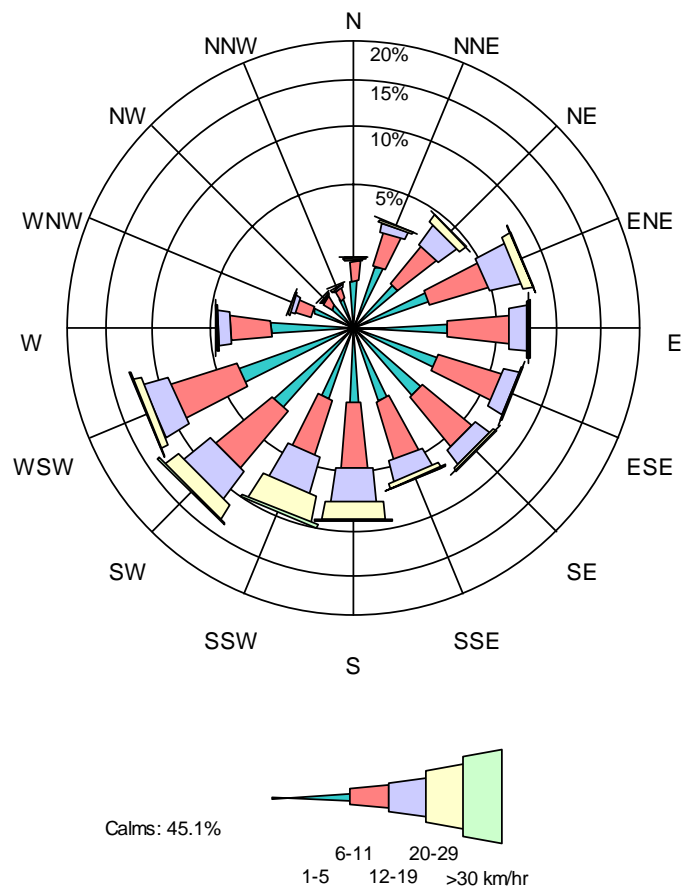
Based on three years of data (2001 to 2003), hourly temperatures at Toamasina ranged from 13.9°C in July 2001 to 35.6°C in January 2002 with an annual average temperature of 24°C.

Toamasina receives rain year-round. The annual average rainfall is over 3,000 mm. The annual average relative humidity is 84% with a minimum value of 40%.

3.4.2.2 Wind Speed and Direction

Figure 4.1-5 shows a windrose of data collected at Toamasina from 2001 to 2003. The predominant wind directions are from the south to the west-southwest sector. The average annual wind speed is 6 km/hr with maximum hourly speeds over 60 km/hr. One significant quality of the winds at Toamasina is the high frequency of calm conditions (45.1%). There is a definite diurnal pattern in the winds where calm conditions (less than 3 km/hr) typically occur at night. The Toamasina station location and data were verified by the station chief and the Direction de la Météorologie.

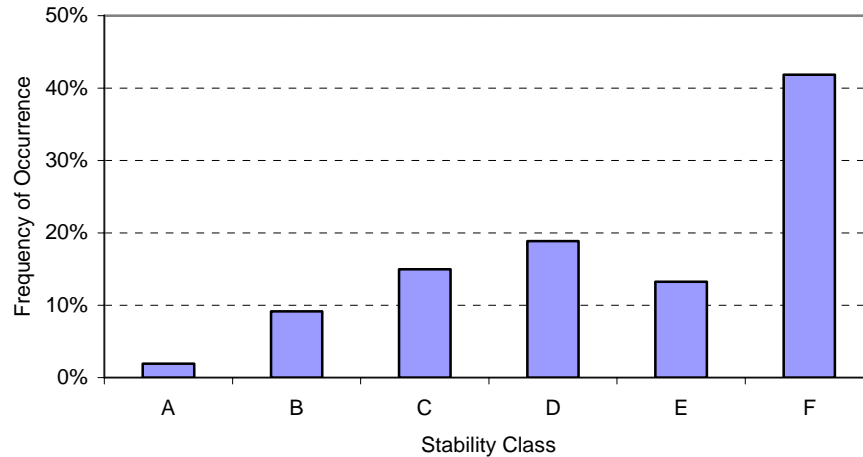
Figure 4.1-5 Toamasina Windrose (2001 to 2003)



3.4.2.3 Atmospheric Stability

The preferred method for calculating atmospheric Pasquill Gifford (PG) stability classes is the Turner method (Turner 1964). This method uses cloud cover, ceiling height and wind speed data measured at the Toamasina station for 2001 to 2003. Figure 4.1-6 provides a histogram showing the frequency of the derived PG stability classes. During these years of observed meteorological data, unstable conditions occurred about 26% of the time, neutral conditions occurred 19% of the time, and stable conditions accounted for the remaining 55% of the observations.

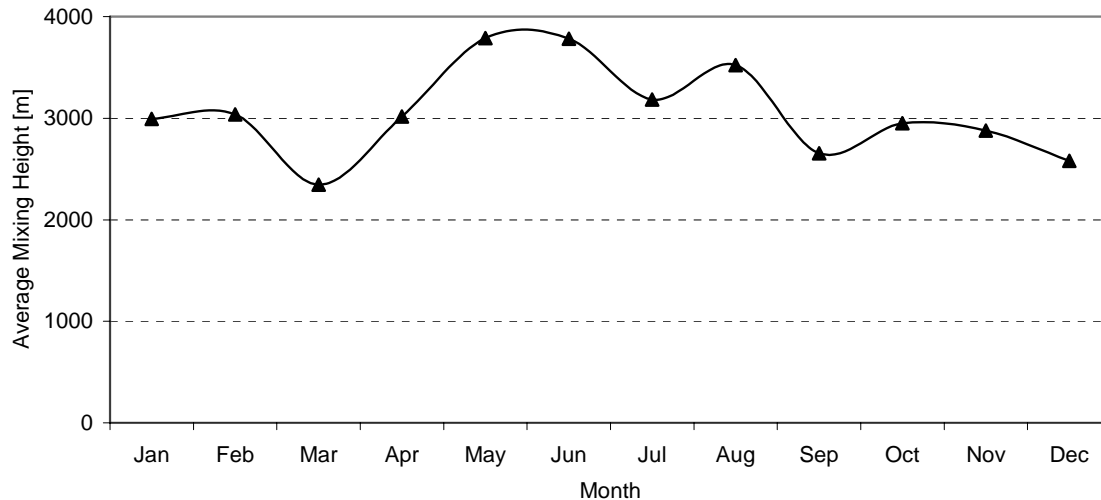
Figure 4.1-6 Frequency of Pasquill-Gifford Stability Conditions at Toamasina (2001 to 2003)



3.4.2.4 Mixing Heights

A monthly summary of calculated mixing heights at Toamasina for stability classes A to D is provided in Figure 4.1-7. Mixing heights were set to unlimited for stable conditions (E and F). The lowest average mixing height of about 2,300 m above ground occurs in March, while the highest average of about 3,900 m above ground occurs in May. These values are representative of the equatorial region where strong heating results in significant vertical mixing which can result in very large mixing heights. Emissions from the process plant are not likely to reach these heights since other factors such as stack exit velocity and temperature will play a more significant role in the dispersion of these emissions.

Figure 4.1-7 Monthly Average Mixing Heights at Toamasina (2001 to 2003)



3.4.3 Ambient Air Quality

There is limited air quality information available for Toamasina; however, a review of air quality in other African countries showed that SO₂ and particulate matter concentrations were usually an issue in populated areas where low-grade coal and wood were used as fuel (Engelbrecht et al. 2001, Emberson et al. 2001). The World Health Organization (WHO) states that the average concentration of PM₁₀ in urban centers in Madagascar is between 21 and 25 µg/m³ (website: WHO 2005). The World Bank annual guideline for particulate matter is 50 µg/m³.

3.5 TAILINGS FACILITY

3.5.1 Climate

Due to the proximity of the tailings facility to the process plant and Toamasina, the climate at the tailings facility is similar to the process plant site (see Section 3.4.1).

3.5.2 Meteorology

Since the tailings facility is located close to the process plant site and Toamasina, and the local topography is relatively flat, local weather patterns are expected to be similar to weather at the process plant site and Toamasina (see Section 3.4.2).

3.5.3 Ambient Air Quality

The ambient air quality in the rural regions of Madagascar is expected to be very good due to the lack of industrial activities. The ambient air quality near the proposed tailings facility is expected to be good due to the lack of industry in the vicinity. Air emissions from Toamasina have not been observed to greatly affect air quality at the tailings facility under baseline conditions. The discussion of the SENES (2001) study provided in Section 3.2.3 also applies here.

3.6 PORT EXPANSION

3.6.1 Climate

The climate of Toamasina, where the port expansion will be located, is described in Section 3.4.1.

3.6.2 Meteorology

The local weather in Toamasina is described in Section 3.4.2.

3.6.3 Ambient Air Quality

Ambient air quality is discussed in Section 3.4.3.

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**VOLUME I
APPENDIX 4.2**

**AMBATOVY PROJECT
AIR QUALITY ASSESSMENT METHODS**

**Submitted to:
Dynatec Corporation**

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1 INTRODUCTION

This document provides the reader with technical information regarding the assessment of air quality effects associated with the mine and process plant of the Ambatovy Project (the project). This document provides the following items:

- a description of the dispersion modelling methods, including receptor locations and dispersion meteorology;
- information used in determining air emissions from the operation phases of the mine and process plant;
- the air quality predictions for SO₂, NO₂, TSP, PM₁₀, H₂S and trace metals where applicable; and
- air quality predictions for additional scenarios not assessed in the Environmental Assessment (EA).

2 DISPERSION MODELLING APPROACH

This section provides more details on the air dispersion modelling approach including dispersion model selection, selection of receptor locations, NO_x to NO₂ conversion, a summary of the dispersion meteorological data and dispersion modelling results.

2.1 MODEL SELECTION

Air dispersion models are predictive tools that use available information regarding the facility emissions and the meteorological conditions to estimate possible ground-level concentrations. The selection of a dispersion model to be used as part of the air quality assessment should be able to satisfy the following key conditions:

- evaluates the various source types present at the project (i.e., point and area sources);
- predicts the necessary ground-level concentrations for different averaging periods (i.e., 1-hour, 24-hour and annual);
- simulates the deposition and scavenging of particles from the atmosphere;
- simulates the chemical transformation of sulphur and nitrogen compounds required for predicting secondary particulates; and
- has a technical basis that is scientifically sound and is in keeping with the current understanding of the dispersion processes in the atmosphere.

Numerical dispersion models simplify small-scale atmospheric motions and turbulence, which limits their capability to replicate individual events. Therefore, these models must predict concentration and deposition patterns for a given set of meteorological parameters. Furthermore, the modelling cannot deal with hour-to-hour variations in the emission rates that may occur during the life of the project.

The steady-state (2-D) version of the CALPUFF dispersion model was determined to be the best model for assessing the air emissions from the project. This model has several advantages that make it ideal for use, namely:

- the ability to model zero wind speed conditions;
- the ability to assess concentrations in complex terrain;
- the ability to accurately predict particulate and acid deposition and the effect on airborne concentrations;

- the ability to accurately predict concentrations in the regional communities, some of which are located more than 10 km from either the mine or the process plant;
- the ability to simulate the variable dust emissions associated with wind erosion (wind-eroded dust will be restricted to periods of relatively high wind speeds); and
- the ability to model the chemical transformations of the emitted SO₂ and NO_x.

2.2 RECEPTORS

Ground-level concentrations were modelled at selected locations within the study area. The selected locations (called receptors) vary depending on the project component (e.g., plant site) and are described below in detail in Sections 3.1 and 4.1.

2.3 NO_x TO NO₂ CONVERSION METHODS

Emissions of oxides of nitrogen (NO_x) from combustion sources are a mixture of nitric oxide (NO) and nitrogen dioxide (NO₂). Nitric oxide (NO) is an unstable component and reacts in the atmosphere to form NO₂. Since the ambient air quality standards are based on the NO₂ concentrations, estimating the fraction of the NO that has transformed into NO₂ can be important.

One method to determine the fraction of the NO that is converted to NO₂ is the ozone limiting method (OLM). The OLM assumes that about 10% of the NO_x emissions are in the form of NO₂, with the balance being in the form of NO. The NO is assumed to rapidly react with ambient levels of ozone (O₃) to form additional NO₂. The following OLM formulation is based on the work of Cole and Summerhays (1979):

$$[NO_2] = [O_3] + 0.1 \times [NO_x] \quad [1]$$

where:

[NO ₂]	=	the nitrogen dioxide concentration [ppm]
[O ₃]	=	the ambient ozone concentration [ppm]
[NO _x]	=	the concentration of oxides of nitrogen [ppm]

Since no site-specific ozone data are available, surface ozone monitoring data from Réunion Island were used (Bhugwant, et al. 2001). The results at the project site are expected to be comparable to Réunion Island since both are located in the southern Indian Ocean and have similar climates. The annual

ozone value was calculated to be 32 ppb based on seasonal observations. For the purposes of this assessment, 1-hour and 24-hour NO₂ concentrations were calculated using ozone values of 22 and 27 ppb, respectively.

2.4 ACID DEPOSITION

Deposition includes both wet and dry processes and can result in the long-term accumulation of compounds in aquatic and terrestrial ecosystems. Wet processes involve the removal of emissions vented into the atmosphere by precipitation. Dry processes involve the removal by direct contact with surface features (e.g., vegetation). Both wet and dry deposition values are expressed as a flux in units of “kg/ha/yr”.

Because several chemical species of nitrogen, sulphur and base cations are considered in the estimate of deposition, the flux is expressed in “keq/ha/yr” where “keq” refers to the number of equivalent hydrogen ions (1 keq = 1 kmol H⁺). For sulphur species, each molecule is equivalent to two hydrogen ions. Each molecule of nitrogen species is equivalent to one hydrogen ion. The deposition of sulphur and nitrogen compounds to these systems has been associated with changes in water and soil chemistry, and with the acidification of water and soil.

Potential acidic input (PAI) is a means of evaluating the level of acidic deposition. The calculation of the PAI is based on the wet and dry deposition of sulphur compounds (e.g., SO₂ gas, SO₄²⁻ particle), nitrogen compounds (e.g., NO gas, NO₂ gas, HNO₃ gas, NO₃⁻ particle) and base cations (e.g., Ca²⁺ particle, Mg⁺ particle and K⁺ particle). Due to the lack of information on base cation emissions, these were not included in the assessment of PAI for the Project. This provides a more conservative prediction of PAI since the neutralizing effects of base cations were not included.

2.5 DISPERSION METEOROLOGY

Meteorology plays an important role in the transport, dispersion and deposition of atmospheric emissions in the region. However, meteorology across the region is influenced by numerous factors that include local topography and vegetation. A meteorological station was installed at the mine site in 1996 and collected data were used in the dispersion modelling for the mine site. Meteorological data from Toamasina was used in the dispersion modelling of the process plant. The data are summarized in Section 3.2.

3 MINE

3.1 RECEPTORS

Ground-level concentrations and deposition rates were modelled at selected locations within the mine site modelling domain. The locations (referred to as receptors), were distributed as follows:

- 50 m spacing within 0.6 km of the mine site (i.e., location of generators);
- 100 m spacing covering the mine footprint;
- 250 m spacing from 5 km to 6 km from the slurry plant site;
- 500 m spacing from 6 km to 8 km from the slurry plant site; and
- 1 km spacing out to the edge of the modelling domain.

Additional 50 m and 250 m spaced receptors were placed at the Mangoro River water intake site. In total, 7,271 regional receptors were included in the dispersion modelling for the mine.

Additional receptors were also placed at selected communities in the region (Table 4.2-1). The modelled receptors are shown graphically in Figure 4.2-1.

3.2 DISPERSION METEOROLOGY

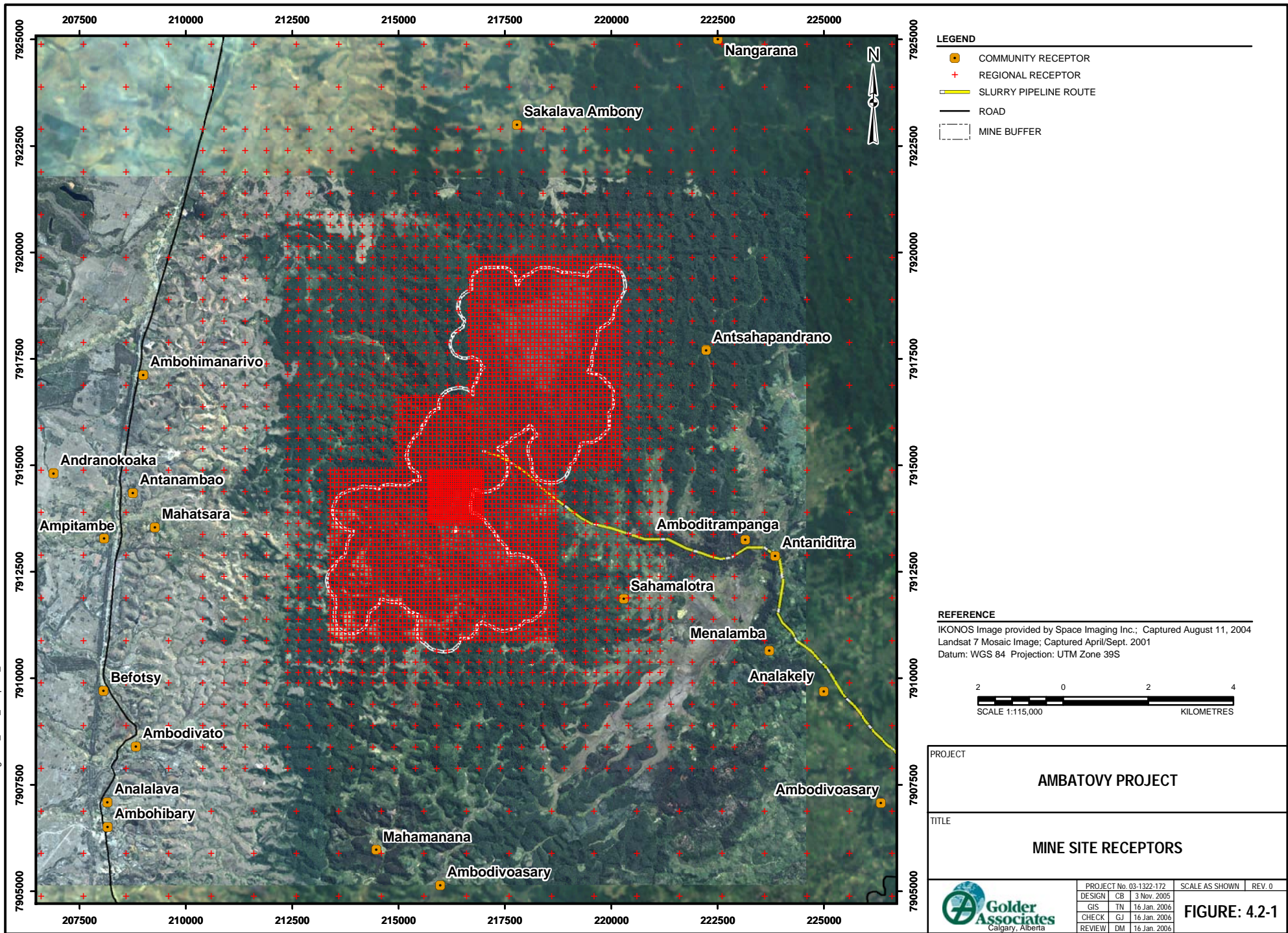
Two meteorological towers were installed at the mine site in 1996. One station was installed at a lower elevation along Route Nationale (RN) 44 west of the mine site and was decommissioned in 2001. The other station is still in operation at the exploration camp site on top of the ridge at the Ambatovy ore body. Two years (1997 and 2002) of data from the exploration camp site station are the most complete (less than 10% missing data); therefore, this data was used in the dispersion modelling.

Table 4.2-1 Mine Site Community Receptors

Community	Distance [km]	Direction
Amboditrampanga	6.9	E
Ambodivato	9.6	SW
Ambodivoasary (1)	9.2	S
Ambodivoasary (2)	12.3	SE
Ambohibary	11.3	SW
Ambohimanarivo	7.9	WNW
Ampitambe	8.4	W
Analakely	9.8	ESE
Analalava	10.9	SW
Andranokoaka	9.5	W
Antanambao	7.6	W
Antaniditra	7.6	E
Antsahapandrano	6.8	ENE
Befotsy	9.5	WSW
Mahamanana	8.6	SSW
Mahatsara	7.1	W
Menalamba	8.2	ESE
Nangarana	12.3	NNE
Sahamalotra	4.6	ESE
Sakalava Ambony	8.8	N

Note: Distance and direction relative to slurry processing area.

L:\2003\03-1322\03-1322-172\mxd\Air\Fig4.2-1_mine_receptors_85x11.mxd



3.2.1.1 Temperature, Precipitation and Relative Humidity

Based on data from 1997 to 2004, hourly temperatures at the exploration camp station ranged from 7.6°C to 31.1°C with an annual average temperature of 17°C. The exploration camp is about 1.5°C cooler than the RN44 station because of its higher elevation. The average annual temperature at the RN44 station, based on data from 1997 to 2001, was 18.5°C.

Annual average rainfall at the mine site was about 1,400 mm with almost 70% occurring from December to March. The RN44 station received 963 mm of rain in 1997 (rainfall data from 1998 to 2001 were incomplete).

The annual average humidity at the exploration camp was 95% with minimum values between 30 and 40%. The average relative humidity at the RN44 station was about 90% with minimum values around 25%.

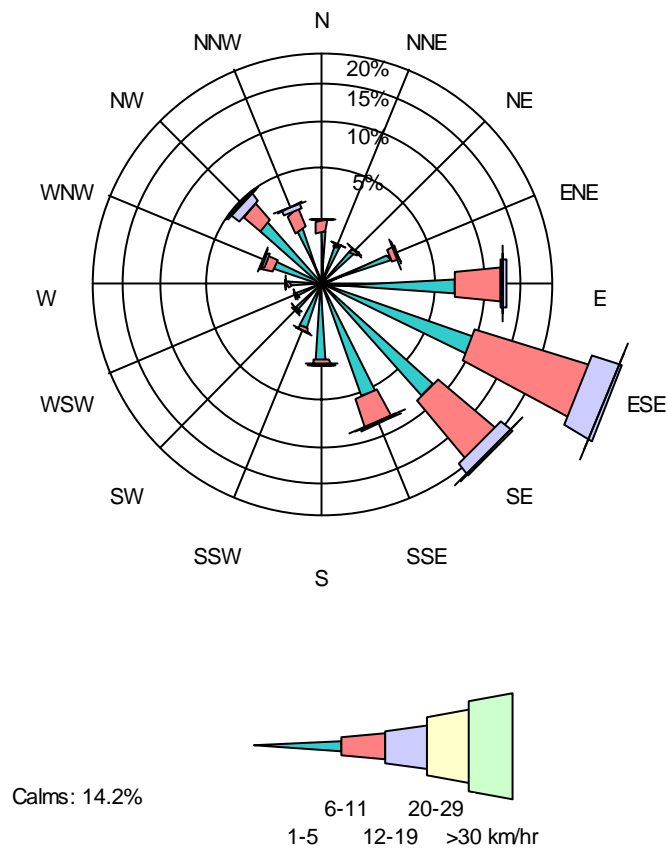
3.2.1.2 Wind Speed and Direction

Figure 4.2-2 shows a windrose at the exploration camp from 1997 to 2004. The windrose consists of bars whose length indicates the frequency of winds blowing from a given direction. The bars are also broken into sections, each of which defines a speed range. A longer section indicates that winds blow more frequently within a given speed range for that direction. East-southeast and southeast winds were predominant and occurred 59% of the time excluding calms. The average annual wind speed was 6 km/hr with maximum hourly speeds of up to 48 km/hr and gust speeds over 80 km/hr. There was also a high frequency of calm conditions (14.2%).

3.2.1.3 Atmospheric Stability

Atmospheric stability is an indirect measure of atmospheric turbulence. The amount of atmospheric turbulence determines how quickly emissions are dispersed and mixed as they are transported by the wind. Turbulence can be generated by either mechanical or thermal mechanisms. Surface heating or cooling by solar radiation contributes to the generation or suppression of thermal turbulence, while high wind speeds contribute to the generation of mechanical turbulence.

Figure 4.2-2 Mine Site Exploration Camp Windrose (1997 to 2004)



One generalized scheme to classify atmospheric stability was developed by Pasquill and Gifford (Pasquill 1961) (referred to as Pasquill-Gifford, or PG, stability classes). The classification scheme comprises six categories: Classes A, B and C (Unstable); Class D (Neutral); and Classes E and F (Stable). These stability classes are used in air dispersion modelling, in conjunction with other meteorological parameters, to determine how air emissions are dispersed. A description of these categories is provided below:

- Unstable conditions are primarily associated with daytime heating conditions, which result in enhanced turbulence levels (i.e., convection) and enhanced dispersion of airborne emissions.
- Neutral conditions are associated with moderate to high wind speeds or overcast conditions, which temper the amount of radiation cooling and heating. Dispersion under neutral conditions is affected more by mechanical turbulence (wind speed) than by surface heating or cooling.

- Stable conditions often occur as a result of nighttime cooling. This results in suppressed turbulence levels and weaker dispersion of airborne emissions.

The preferred method of calculating PG stability classes is the Turner method (Turner 1964); however, this method requires cloud cover and ceiling height data which are not available at the mine site. Therefore, a modified version of the solar radiation/delta-T (SRDT) method from the United States U.S. Environmental Protection Agency (USEPA) was used to calculate stability classes (USEPA 2000). This method uses wind speed and solar radiation measured at the exploration camp station. The relationship between the PG stability classes, solar radiation and wind speed during the day is given in Table 4.2-2. At night, if the wind speed was greater than or equal to 2.5 m/s then the stability class was set to D. If night time wind speeds were less than 2.5 m/s, the stability class was set to F.

Table 4.2-2 Key to Solar Radiation Delta-T (SRDT) Method for Estimating Pasquill-Gifford Stability Categories (Daytime)

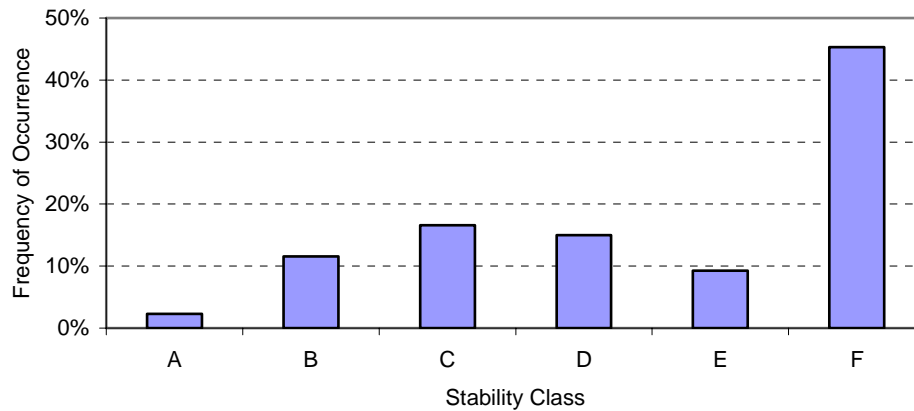
Wind Speed [m/s]	Solar Radiation [W/m ²]			
	≥ 925	925-675	675-175	< 175
< 2	A	A	B	D
2-3	A	B	C	D
3-5	B	B	C	D
5-6	C	C	D	D
≥ 6	C	D	D	D

Source: USEPA 2000.

W/m² = watts per square metre.

Figure 4.2-3 provides a histogram showing the frequency of the derived PG stability classes. Stability classes were calculated for the two years which had the most complete data (1997 and 2002). During these years, unstable conditions occurred about 30% of the time, neutral conditions occurred 15% of the time, and stable conditions accounted for the remaining 55% of the observations.

Figure 4.2-3 Frequency of Pasquill-Gifford Stability Conditions at the Mine Site (1997 and 2002)



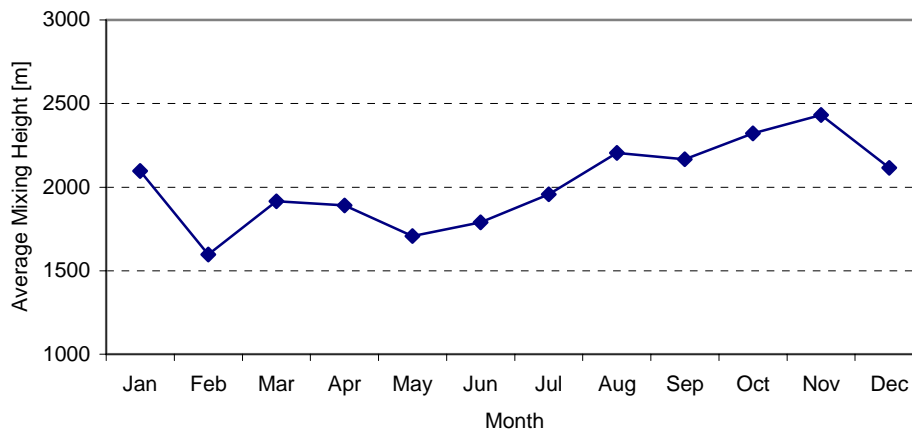
3.2.1.4 Mixing Heights

The atmospheric mixing height is the relative elevation above the surface of the lower atmosphere where the majority of dispersion occurs. The height of this layer depends on surface heating and wind turbulence. Low mixing heights can reduce dispersion and result in elevated ground-level concentrations.

Ideally, mixing heights are determined from vertical profiles of wind speed and temperature and comprehensive surface data. When such data is unavailable, other methods can be used to calculate mixing heights. Since vertical profiles of winds and temperature were not available for the mine site, mixing heights were calculated from the observed surface wind speed following accepted methods from USEPA (2000) and Randerson (1984).

Figure 4.2-4 provides a monthly summary of calculated mixing heights at the mine site for the years 1997 and 2002 and for stability classes A to D. Mixing heights were set to unlimited for stable conditions (E and F). The lowest average mixing height of 1,600 m above ground occurs in February, while the highest average of about 2,400 m above ground occurs in November. These values are representative of the equatorial region where strong heating results in significant vertical mixing which can result in very large mixing heights. Emissions from the mine site are not likely to reach these heights since other factors such as stack exit velocity and temperature will play a more significant role in the dispersion of these emissions.

Figure 4.2-4 Monthly Average Mixing Heights at the Mine Site (1997 and 2002)



3.3 MINE EMISSIONS

This section provides a summary of the information used to develop the emissions inventory for the emissions at the project. The objective of this section is to identify and document the basis for the emissions information used in the air quality assessment.

Table 4.2-3 presents detailed information regarding the emission factors, project base quantities, and emission controls used to estimate emissions from the project. Table 4.2-4 summarizes the emissions of SO₂, NO_x, PM₁₀ and TSP from the mine.

3.3.1 Variable Eroded Dust

During periods of high wind speeds, it is possible for dust to be eroded from exposed areas of the project. While the emissions due to these events can be calculated accurately, it is difficult to model the releases accurately. However, the CALPUFF dispersion model allows the user to input a threshold wind velocity, below which the emissions of wind blown dust will not occur. In assessing the particulate releases from the project, it was determined that wind erosion of the exposed areas would occur when the wind speeds exceeded 10 m/s. Such wind speeds were observed to occur at the project site only 20 hours during the year. These high wind speeds usually only occur during the rainy season when suspended dust would be minimal. Therefore, wind-blown dust from the mine was not included in the air quality assessment.

Table 4.2-3 Summary of Emission Information at the Mine

Activity	Information Used
Power Generation – Power Plant	
emission factors	<p>SO₂ emissions calculated based on diesel fuel sulphur content of 5,000 ppmw from the May 18, 2005 telephone conversation between Golder and Dynatec</p> <p>NO_x emission factor of 3.2 lb/MMBtu from Table 3.4-1, §3.4, of USEPA AP-42 (USEPA 1995)</p> <p>CO emission factor of 0.85 lb/MMBtu from Table 3.4-1, §3.4, of USEPA AP-42 (USEPA 1995)</p> <p>TSP emission factor of 0.1 lb/MMBtu from Table 3.4-1, §3.4, of USEPA AP-42 (USEPA 1995)</p> <p>PM₁₀ emission factor of 0.0822 lb/MMBtu calculated based on TSP emission factor of 0.1 lb/MMBtu, total filterable and condensable PM₁₀ emission factor of 0.0573 lb/MMBtu, and total filterable and condensable PM emission factor of 0.0697 lb/MMBtu from Tables 3.4-1 and 3.4-2, §3.4, of USEPA AP-42 (USEPA 1995)</p> <p>PM_{2.5} emission factor of 0.0798 lb/MMBtu calculated based on TSP emission factor of 0.1 lb/MMBtu, filterable PM_{2.5} emission factor of 0.0479 lb/MMBtu, condensable PM_{2.5} emission factor of 0.0077 lb/MMBtu, and total filterable and condensable PM emission factor of 0.0697 lb/MMBtu from Tables 3.4-1 and 3.4-2, §3.4, of USEPA AP-42 (USEPA 1995)</p> <p>CO₂ emission factor of 3,257 t/10³ t calculated based on diesel fuel heating value, C emission factor of 20.0 t/TJ, and oxidized fraction of C of 0.99 from Tables 1-4 and 1-6, Chapter 1.4, of <u>Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual</u> (IPCC 1996)</p> <p>CH₄ emission factor of 3 kg/TJ from Table 1-7, Chapter 1.4, of <u>Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual</u> (IPCC 1996)</p> <p>N₂O emission factor of 0.6 kg/TJ from Table 1-8, Chapter 1.4, of <u>Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual</u> (IPCC 1996)</p> <p>PAH emission factor of 2.12 × 10⁻⁴ lb/MMBtu from Table 3.4-4, §3.4, of USEPA AP-42 (USEPA 1995)</p> <p>VOC emission factor of 0.0819 lb/MMBtu calculated based on TOC emission factor of 0.09 lb/MMBtu and nonmethane weight percent of 91% from Table 3.4-1, §3.4, of USEPA AP-42 (USEPA 1995)</p>
base quantities	<p>three diesel generators utilized for power generation and one diesel generator held as backup as provided in the June 17, 2005 e-mail</p> <p>diesel fuel consumption of 458.5 L/h-unit from the Gen Set Performance Data as provided in the June 17, 2005 e-mail</p> <p>diesel fuel density of 0.876 t/m³ as provided in the June 17, 2005 e-mail</p> <p>diesel generator power rating of 1991.6 kW from the Gen Set Performance Data and efficiency of 35% as provided in the June 17, 2005 e-mail</p> <p>diesel fuel heating value of 19,300 Btu/lb from Table 3.4-1 Note a, §3.4, of USEPA AP-42 (USEPA 1995)</p>
emission controls	no emission controls assumed

Table 4.2-3 Summary of Emission Information at the Mine (continued)

Activity	Information Used
Power Generation – Mangoro Water Intake	
emission factors	<p>SO₂ emissions calculated based on diesel fuel sulphur content of 5,000 ppmw from the May 18, 2005 telephone conversation between Golder and Dynatec</p> <p>NO_x emission factor of 3.2 lb/MMBtu from Table 3.4-1, §3.4, of USEPA AP-42 (USEPA 1995)</p> <p>CO emission factor of 0.85 lb/MMBtu from Table 3.4-1, §3.4, of USEPA AP-42 (USEPA 1995)</p> <p>TSP emission factor of 0.1 lb/MMBtu from Table 3.4-1, §3.4, of USEPA AP-42 (USEPA 1995)</p> <p>PM₁₀ emission factor of 0.0822 lb/MMBtu calculated based on TSP emission factor of 0.1 lb/MMBtu, total filterable and condensable PM₁₀ emission factor of 0.0573 lb/MMBtu, and total filterable and condensable PM emission factor of 0.0697 lb/MMBtu from Tables 3.4-1 and 3.4-2, §3.4, of USEPA AP-42 (USEPA 1995)</p> <p>PM_{2.5} emission factor of 0.0798 lb/MMBtu calculated based on TSP emission factor of 0.1 lb/MMBtu, filterable PM_{2.5} emission factor of 0.0479 lb/MMBtu, condensable PM_{2.5} emission factor of 0.0077 lb/MMBtu, and total filterable and condensable PM emission factor of 0.0697 lb/MMBtu from Tables 3.4-1 and 3.4-2, §3.4, of USEPA AP-42 (USEPA 1995)</p> <p>CO₂ emission factor of 3,257 t/10³ t calculated based on diesel fuel heating value, C emission factor of 20.0 t/TJ, and oxidized fraction of C of 0.99 from Tables 1-4 and 1-6, Chapter 1.4, of <u>Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual</u> (IPCC 1996)</p> <p>CH₄ emission factor of 3 kg/TJ from Table 1-7, Chapter 1.4, of <u>Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual</u> (IPCC 1996)</p> <p>N₂O emission factor of 0.6 kg/TJ from Table 1-8, Chapter 1.4, of <u>Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual</u> (IPCC 1996)</p> <p>PAH emission factor of 2.12 × 10⁻⁴ lb/MMBtu from Table 3.4-4, §3.4, of USEPA AP-42 (USEPA 1995)</p> <p>VOC emission factor of 0.0819 lb/MMBtu calculated based on TOC emission factor of 0.09 lb/MMBtu and nonmethane weight percent of 91% from Table 3.4-1, §3.4, of USEPA AP-42 (USEPA 1995)</p>
base quantities	<p>one 1-MW diesel generator utilized for power generation as provided in the July 25, 2005 e-mail</p> <p>diesel fuel consumption of 279.0 L/h-unit from a typical 1-MW diesel generator set specifications sheet</p> <p>diesel fuel density of 0.876 t/m³ as provided in the June 17, 2005 e-mail</p> <p>diesel generator efficiency of 35% as provided in the June 17, 2005 e-mail</p> <p>diesel fuel heating value of 19,300 Btu/lb from Table 3.4-1 Note a, §3.4, of USEPA AP-42 (USEPA 1995)</p>
emission controls	no emission controls assumed

Table 4.2-3 Summary of Emission Information at the Mine (continued)

Activity	Information Used
Mine Fleet Exhaust	
emission factors	<p>SO₂ emissions calculated based on diesel fuel sulphur content of 5,000 ppmw from the May 18, 2005 telephone conversation between Golder and Dynatec</p> <p>NO_x, CO, PM, and VOC emissions calculated based on Tier 2 emission factors, as advised in the September 6, 2005 e-mail</p> <p>Tier 2 NO_x, CO, PM, and VOC emission factors from Table 1 of <u>Control of Emissions of Air Pollution From Nonroad Diesel Engines: Final Rule</u> (Federal Register, Vol. 63, No. 205, USEPA October 23, 1998)</p> <p>NO_x Tier 2 emission factor of 5.8 g/kW-h calculated based on Tier 2 NMHC + NO_x emission factor of 6.6 g/kW-h, Tier 1 NO_x emission factor of 9.2 g/kW-h, Tier 1 HC emission factor of 1.3 g/kW-h, and the assumption of NMHC = 0.98HC for power ratings ≥ 130 kW</p> <p>NO_x Tier 2 emission factor of 5.6 g/kW-h calculated based on Tier 2 NMHC+NO_x emission factor of 6.4 g/kWh, Tier 1 NO_x emission factor of 9.2 g/kW-h, Tier 1 HC emission factor of 1.3 g/kW-h, and the assumption of NMHC = 0.98HC for power ratings ≥ 225 kW</p> <p>CO Tier 2 emission factor of 3.5 g/kW-h for power ratings ≥ 130 kW</p> <p>PM Tier 2 emission factor of 0.20 g/kW-h for power ratings ≥ 130 kW</p> <p>particle size assumed to be less than 2.5 µm for all PM, therefore PM_{2.5}, PM₁₀, and TSP emissions assumed to be the same</p> <p>VOC Tier 2 emission factor of 0.82 g/kW-h calculated based on Tier 2 NMHC + NO_x emission factor of 6.6 g/kW-h, Tier 1 NO_x emission factor of 9.2 g/kW-h, Tier 1 HC emission factor of 1.3 g/kW-h, and the assumption of NMHC = 0.98HC for power ratings ≥ 130 kW</p> <p>VOC Tier 2 emission factor of 0.79 g/kW-h calculated based on Tier 2 NMHC+NO_x emission factor of 6.4 g/kWh, Tier 1 NO_x emission factor of 9.2 g/kW-h, Tier 1 HC emission factor of 1.3 g/kW-h, and the assumption of NMHC = 0.98HC for power ratings ≥ 225 kW</p> <p>load factors of 0.43 for the drill and 0.59 for other equipment, except for the hydraulic shovel, from Appendix A of <u>Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling</u>, EPA420-P-04-005 (USEPA April 2004)</p> <p>load factor of 1 assumed for the hydraulic shovel</p> <p>CO₂ emission factor of 3,257 t/10³ t calculated based on diesel fuel heating value, C emission factor of 20.0 t/TJ, and oxidized fraction of C of 0.99 from Tables 1-4 and 1-6, Chapter 1.4, of <u>Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual</u> (IPCC 1996)</p> <p>CH₄ emission factor of 5 kg/TJ from Table 1-7, Chapter 1.4, of <u>Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual</u> (IPCC 1996)</p> <p>N₂O emission factor of 0.6 kg/TJ from Table 1-8, Chapter 1.4, of <u>Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual</u> (IPCC 1996)</p> <p>PAH emission factor of 0.0044 kg/10³ L from Table 3-51 of <u>Technical Reference for the Meteorology, Emissions and Ambient Air Quality in the Athabasca Oil Sands Region</u> (Golder Associates Ltd. and Concor Pacific Environmental Technologies Inc. May 1998)</p> <p>NH₃ emission factor of 428.85 mg/gal calculated based on gasoline non-catalyst emission factor of 111.03 mg/gal, heavy-duty diesel emission factor of 27.037 mg/mi, and light-duty gasoline, noncatalyst emission factor of 7.0 mg/mi from Tables III-3 and III-5 of <u>Estimating Ammonia Emissions from Anthropogenic Nonagricultural Sources – Draft Final Report</u> (U.S. EIIP April 2004)</p>

Table 4.2-3 Summary of Emission Information at the Mine (continued)

Activity	Information Used
base quantities	<p>maximum diesel fuel consumption of 14,753 t/yr calculated based on the average diesel fuel consumption of 11,137 t/yr, as provided in the June 16, 2005 e-mail, and the average and maximum total operating hours of 191,599 h/yr and 253,800 h/yr, respectively, as derived from the draft <u>Ambatovy Nickel Project Feasibility Study</u> (SNC-Lavalin November 2004)</p> <p>mine fleet information including equipment type and number of equipment per mining year based on the draft <u>Ambatovy Nickel Project Feasibility Study</u> (SNC-Lavalin November 2004)</p> <p>equipment power ratings from manufacturers' data</p> <p>operating time of 720 min/shift and number of shifts per mining year for each equipment from the draft <u>Ambatovy Nickel Project Feasibility Study</u> (SNC-Lavalin November 2004)</p> <p>operating days of 355 d/yr for the Caterpillar 992G wheel loader and 350 d/yr for other equipment from the draft <u>Ambatovy Nickel Project Feasibility Study</u> (SNC-Lavalin November 2004)</p> <p>diesel fuel heating value of 19,300 Btu/lb from Table 3.4-1 Note a, §3.4, of USEPA AP-42 (USEPA 1995)</p> <p>diesel fuel density of 0.876 t/m³ from the June 17, 2005 e-mail</p> <p>10% assumed as contingency for other mine support equipment</p>
emission controls	Tier 2 emission controls assumed
Road Dust	
emission factors	<p>Cat 777 haul trucks, Cat 740 articulated dump trucks, and Cat 777D water trucks assumed to be the primary source of road dust emissions</p> <p>TSP emission factor of 1,191 g/VKT calculated based on Equations 1a and 2, §13.2.2, of USEPA AP-42 (USEPA 1995)</p> <p>PM₁₀ emission factor of 351.6 g/VKT calculated based on Equations 1a and 2, §13.2.2, of USEPA AP-42 (USEPA 1995)</p> <p>PM_{2.5} emission factor of 53.91 g/VKT calculated based on Equations 1a and 2, §13.2.2, of USEPA AP-42 (USEPA 1995)</p>
base quantities	<ul style="list-style-type: none"> ◆ silt content of 10% from the June 16, 2005 e-mail ◆ mine fleet mean vehicle weight of 112.51 tons based on 22 Cat 777 haul trucks, 4 Cat 740 articulated dump trucks, and 2 Cat 777D water trucks operating simultaneously ◆ loaded and empty weights for the Cat 777 haul trucks and Cat 740 articulated dump trucks from the draft <u>Ambatovy Nickel Project Feasibility Study</u> (SNC-Lavalin November 2004) and weights for the Cat 777D water trucks from manufacturer's data ◆ empty and loaded weights are 64.36 t and 156.46 t, respectively, for the Cat 777 haul trucks, 32.55 t and 66.55 t, respectively, for the Cat 740 articulated dump trucks, and 67.297 t and 163.293 t, respectively, for the Cat 777D water trucks ◆ 295 days in a year with at least 0.254 mm of precipitation from 2002 meteorological data ◆ wet material quantities transferred calculated based on dry material quantities transferred and material moisture contents from the draft <u>Ambatovy Nickel Project Feasibility Study</u> (SNC-Lavalin November 2004) ◆ number of trips travelled based on calculated wet material quantities and wet truck capacities ◆ distances travelled per trip determined based on road sections developed for the transportation of various materials to different locations
emission controls	dust suppression control efficiency of 80% assumed based on wet suppression

Table 4.2-3 Summary of Emission Information at the Mine (continued)

Activity	Information Used
Bulldozing	
emission factors	<p>TSP emission factor of 0.300 kg/h calculated based on TSP emission factor equation in Table 11.9-2, §11.9, of USEPA AP-42 (USEPA 1995), silt content of 10% from the June 16, 2005 e-mail, and weighted average moisture content of 44.1% calculated based on wet material quantities transferred and material moisture contents from the draft <u>Ambatovy Nickel Project Feasibility Study</u> (SNC-Lavalin November 2004)</p> <p>PM₁₀ emission factor of 0.0533 kg/h calculated based on PM₁₅ emission factor equation and PM₁₀/PM₁₅ scaling factor of 0.75 in Table 11.9-2, §11.9, of USEPA AP-42 (USEPA 1995), silt content of 10%, and weighted average moisture content of 44.1%</p> <p>PM_{2.5} emission factor of 0.0315 kg/h calculated based on calculated TSP emission factor of 0.300 kg/h and PM_{2.5}/TSP scaling factor of 0.105 from Table 11.9-2, §11.9, of USEPA AP-42 (USEPA 1995)</p>
base quantities	maximum number of dozers of 7/yr from the draft <u>Ambatovy Nickel Project Feasibility Study</u> (SNC-Lavalin November 2004)
emission controls	no emission controls assumed
Drilling	
emission factors	<p>TSP emission factor of 0.59 kg/hole from Table 11.9-4, §11.9 of USEPA AP-42 (USEPA 1995)</p> <p>PM₁₀ emission factor of 0.28 kg/hole calculated based on TSP emission factor of 0.59 kg/hole, PM₁₀ particle size multiplier of 0.35, and PM₃₀ particle size multiplier of 0.74 from §13.2.4 of USEPA AP-42 (USEPA 1995)</p> <p>PM_{2.5} emission factor of 0.088 kg/hole calculated based on TSP emission factor of 0.59 kg/hole, PM_{2.5} particle size multiplier of 0.11, and PM₃₀ particle size multiplier of 0.74 from §13.2.4 of USEPA AP-42 (USEPA 1995)</p>
base quantities	♦ maximum number of holes of 4,791 holes/yr from the draft <u>Ambatovy Nickel Project Feasibility Study</u> (SNC-Lavalin November 2004)
emission controls	no emission controls assumed
Grading	
emission factors	<p>TSP emission factor of 1.5 kg/VKT calculated based on TSP emission factor equation and an assumed mean vehicle speed of 11.4 kph from Tables 11.9-2 and 11.9-3; §11.9 of USEPA AP-42 (USEPA 1995)</p> <p>PM₁₀ emission factor of 0.44 kg/VKT calculated based on PM₁₅ emission factor equation, PM₁₀/PM₁₅ scaling factor of 0.60, and an assumed mean vehicle speed of 11.4 kph from Tables 11.9-2 and 11.9-3; §11.9 of USEPA AP-42 (USEPA 1995)</p> <p>PM_{2.5} emission factor of 0.046 kg/VKT calculated based on calculated TSP emission factor of 1.5 kg/VKT and PM_{2.5}/TSP scaling factor of 0.031 from Table 11.9-2; §11.9 of USEPA AP-42 (USEPA 1995)</p>
base quantities	♦ maximum number of graders of 2/yr from the draft <u>Ambatovy Nickel Project Feasibility Study</u> (SNC-Lavalin November 2004)
emission controls	control efficiency of 80% assumed due to the high material moisture contents

Table 4.2-3 Summary of Emission Information at the Mine (continued)

Activity	Information Used
Loading/Unloading	
emission factors	<p>loading/unloading TSP emission factors of 1.2×10^{-5} kg/Mg for ore, low grade, and waste, 1.4×10^{-5} kg/Mg for ferricrete, and 3.6×10^{-5} kg/Mg for sheeting calculated based on Equation 1, §13.2.4 of USEPA AP-42 (USEPA 1995), mean wind speed 1.8 m/s from 1997 meteorological data, and material moisture contents from the draft <u>Ambatovy Nickel Project Feasibility Study</u> (SNC-Lavalin November 2004)</p> <p>loading/unloading PM₁₀ emission factors of 5.5×10^{-6} kg/Mg for ore, low grade, and waste, 6.5×10^{-6} kg/Mg for ferricrete, and 1.7×10^{-5} kg/Mg for sheeting calculated based on Equation 1, §13.2.4 of USEPA AP-42 (USEPA 1995), mean wind speed 1.8 m/s from 1997 meteorological data, and material moisture contents from the draft <u>Ambatovy Nickel Project Feasibility Study</u> (SNC-Lavalin November 2004)</p> <p>loading/unloading PM_{2.5} emission factors of 1.7×10^{-6} kg/Mg for ore, low grade, and waste, 2.1×10^{-6} kg/Mg for ferricrete, and 5.4×10^{-6} kg/Mg for sheeting calculated based on Equation 1, §13.2.4 of USEPA AP-42 (USEPA 1995), mean wind speed 1.8 m/s from 1997 meteorological data, and material moisture contents from the draft <u>Ambatovy Nickel Project Feasibility Study</u> (SNC-Lavalin November 2004)</p>
base quantities	maximum quantities of materials handled from the draft <u>Ambatovy Nickel Project Feasibility Study</u> (SNC-Lavalin November 2004)
emission controls	no emission controls assumed

Table 4.2-4 Mine Air Emissions Summary

Source	Emission Rate [t/d]			
	SO ₂	NO _x	PM ₁₀	TSP
Diesel Generators	0.35	2.37	0.06	0.07
Mine Fleet	0.42	1.59	0.06	0.06
Road Dust	—	—	0.21	0.70
Fugitive Dust	—	—	0.06	0.22
Total	0.77	3.96	0.39	1.06

“—” indicates no emissions from this source.

3.3.2 Source Inputs

One of the most important factors in any dispersion modelling evaluation is the source input characteristics used to simulate the ground level concentrations. Tables 4.2-5 and 4.2-6 present the source characteristics for the point and area sources modelled, respectively, in the air quality assessment of the mine.

Table 4.2-5 Mine Point Source Emission Characteristics

Source Name	Source Description	Easting (m)	Northing (m)	Base Elevation (m)	Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/s)	Exit Temperature (K)
DYMINEDGEN01	Mine Power Plant - Diesel Generator01	216,369	7,914,318	1,018.1	15.00	0.492	35.0	668
DYMINEDGEN02	Mine Power Plant - Diesel Generator02	216,369	7,914,286	1,018.0	15.00	0.492	35.0	668
DYMINEDGEN03	Mine Power Plant - Diesel Generator03	216,369	7,914,254	1,017.7	15.00	0.492	35.0	668
DYMINEDGEN04	Mangoro Water Intake - Diesel Generator04	194,604	7,913,345	858.6	10.00	0.203	112.3	705

Table 4.2-6 Mine Area Source Emission Characteristics

Source Name	Source Description	Centre Easting (m)	Centre Northing (m)	Source Area (m ²)	Base Elevation (m)	Initial σ_z (m)
DYMINEAREA01	Mine Fleet Area01	218,590	7,918,423	946,064	1,071.8	4.6
DYMINEAREA02	Mine Fleet Area02	218,892	7,917,748	366,803	1,031.3	4.6
DYMINEAREA03	Mine Fleet Area03	218,384	7,917,215	293,781	1,021.3	4.6
DYMINEAREA04	Mine Fleet Area04	218,477	7,916,863	215,270	986.7	4.6
DYMINEAREA05	Mine Fleet Area05	218,888	7,916,439	653,901	1,008.4	4.6
DYMINEAREA06	Mine Fleet Area06	219,014	7,916,012	294,132	989.3	4.6
DYMINEAREA07	Mine Fleet Area07	216,671	7,913,174	160,727	1,008.4	4.6
DYMINEAREA08	Mine Fleet Area08	216,293	7,913,263	210,516	1,011.3	4.6
DYMINEAREA09	Mine Fleet Area09	215,801	7,913,239	157,217	986.9	4.6
DYMINEAREA10	Mine Fleet Area10	215,271	7,913,497	239,428	983.8	4.6
DYMINEAREA11	Mine Fleet Area11	214,856	7,913,239	361,636	1,003.0	4.6
DYMINEAREA12	Mine Fleet Area12	214,965	7,912,515	208,946	1,025.0	4.6
DYMINEAWSP	Analamay Waste Stockpile	217,524	7,916,501	579,168	1,048.2	4.0
DYMINESUN	Ferricrete Stockpile	217,125	7,912,964	67,901	1,071.1	4.0
DYMINELSUN	Low Grade Stockpile	215,889	7,914,738	1,387,380	1,080.0	4.0

Table 4.2-6 Mine Area Source Emission Characteristics (continued)

Source Name	Source Description	Centre Easting (m)	Centre Northing (m)	Source Area (m ²)	Base Elevation (m)	Initial σ_z (m)
DYMINPLNT	Ore Preparation Plant	216,626	7,914,712	92,280	1,053.3	10.0
DYMINROAD01	Road Dust Area01	218,541	7,917,843	6,092	1,040.5	10.0
DYMINROAD02	Road Dust Area02	218,297	7,917,856	5,677	1,052.8	10.0
DYMINROAD03	Road Dust Area03	218,070	7,917,963	6,008	1,084.0	10.0
DYMINROAD04	Road Dust Area04	217,851	7,917,923	5,368	1,063.7	10.0
DYMINROAD05	Road Dust Area05	217,815	7,917,706	5,188	1,047.9	10.0
DYMINROAD06	Road Dust Area06	217,765	7,917,503	5,045	1,091.8	10.0
DYMINROAD07	Road Dust Area07	217,665	7,917,279	7,075	1,120.9	10.0
DYMINROAD08	Road Dust Area08	217,713	7,917,035	5,980	1,094.6	10.0
DYMINROAD09	Road Dust Area09	218,256	7,916,674	7,300	1,029.1	10.0
DYMINROAD10	Road Dust Area10	218,011	7,916,711	5,301	1,058.9	10.0
DYMINROAD11	Road Dust Area11	217,789	7,916,825	5,724	1,063.9	10.0
DYMINROAD12	Road Dust Area12	217,816	7,916,710	6,791	1,052.5	10.0
DYMINROAD13	Road Dust Area13	217,850	7,916,455	6,536	1,033.4	10.0
DYMINROAD14	Road Dust Area14	217,793	7,916,224	5,486	999.9	10.0
DYMINROAD15	Road Dust Area15	217,606	7,916,059	5,550	1,003.5	10.0
DYMINROAD16	Road Dust Area16	217,402	7,915,910	4,694	1,027.7	10.0
DYMINROAD17	Road Dust Area17	217,192	7,915,778	5,899	1,038.1	10.0
DYMINROAD18	Road Dust Area18	217,039	7,915,868	5,475	1,039.6	10.0
DYMINROAD19	Road Dust Area19	216,954	7,916,102	5,826	1,056.1	10.0
DYMINROAD20	Road Dust Area20	216,787	7,916,262	5,663	1,070.6	10.0
DYMINROAD21	Road Dust Area21	216,559	7,916,371	5,242	1,095.4	10.0
DYMINROAD22	Road Dust Area22	216,368	7,916,350	5,517	1,119.4	10.0
DYMINROAD23	Road Dust Area23	216,411	7,916,179	5,578	1,116.3	10.0
DYMINROAD24	Road Dust Area24	216,487	7,915,993	5,469	1,107.8	10.0
DYMINROAD25	Road Dust Area25	216,440	7,915,746	6,651	1,111.6	10.0
DYMINROAD26	Road Dust Area26	216,985	7,915,634	6,000	1,067.6	10.0

Table 4.2-6 Mine Area Source Emission Characteristics (continued)

Source Name	Source Description	Centre Easting (m)	Centre Northing (m)	Source Area (m ²)	Base Elevation (m)	Initial σ_z (m)
DYMINEROAD27	Road Dust Area27	216,845	7,915,426	5,730	1,109.5	10.0
DYMINEROAD28	Road Dust Area28	216,902	7,915,213	5,517	1,107.5	10.0
DYMINEROAD29	Road Dust Area29	217,100	7,915,058	5,500	1,107.1	10.0
DYMINEROAD30	Road Dust Area30	217,122	7,914,873	5,708	1,104.6	10.0
DYMINEROAD31	Road Dust Area31	216,937	7,914,808	6,148	1,097.9	10.0
DYMINEROAD32	Road Dust Area32	216,290	7,913,845	6,811	997.9	10.0
DYMINEROAD33	Road Dust Area33	216,271	7,913,599	5,486	996.7	10.0
DYMINEROAD34	Road Dust Area34	216,141	7,913,446	5,376	992.6	10.0
DYMINEROAD35	Road Dust Area35	216,005	7,913,530	7,591	1,015.3	10.0
DYMINEROAD36	Road Dust Area36	215,871	7,913,699	5,626	1,023.1	10.0
DYMINEROAD37	Road Dust Area37	215,732	7,913,603	6,780	1,001.4	10.0
DYMINEROAD38	Road Dust Area38	215,595	7,913,546	5,475	993.9	10.0
DYMINEROAD39	Road Dust Area39	216,220	7,914,071	5,769	1,029.3	10.0
DYMINEROAD40	Road Dust Area40	216,191	7,914,309	5,851	1,045.9	10.0
DYMINEROAD41	Road Dust Area41	216,206	7,914,557	5,840	1,043.4	10.0
DYMINEROAD42	Road Dust Area42	216,380	7,914,070	5,306	1,009.4	10.0
DYMINEROAD43	Road Dust Area43	216,461	7,914,308	6,126	1,014.4	10.0
DYMINEROAD44	Road Dust Area44	216,524	7,914,549	6,550	1,029.7	10.0
DYMINEROAD45	Road Dust Area45	216,666	7,914,759	5,129	1,062.7	10.0
DYMINEROAD46	Road Dust Area46	216,377	7,913,836	5,480	991.9	10.0
DYMINEROAD47	Road Dust Area47	216,524	7,913,636	5,368	1,005.1	10.0
DYMINEROAD48	Road Dust Area48	216,721	7,913,483	5,227	1,018.3	10.0
DYMINEROAD49	Road Dust Area49	216,890	7,913,293	5,519	1,017.8	10.0
DYMINEROAD50	Road Dust Area50	217,014	7,913,078	5,783	1,055.6	10.0

3.4 AIR QUALITY PREDICTIONS

The expected emissions of SO₂, NO_x, TSP, PM₁₀ and trace metals from the operation of the mine were used as inputs to the CALPUFF dispersion model to predict ground-level concentrations within the study area and at regional communities. The CALPUFF model was run in the steady-state (2-D) mode using two years of on-site meteorological observations. A listing of dispersion modelling source inputs is presented in Section 3.3-2. The results of the modelling are presented in the following sections. All modelling results have been presented excluding a 300 m buffer around the mine footprint. This buffer is consistent with the area used in the socio-economic assessment, wherein any people living this close to the mine, would be helped to re-settle.

3.4.1 Sulphur Dioxide

Table 4.2-7 presents the maximum SO₂ predictions resulting from activities at the mine. The maximum 24-hour and annual concentrations within the study area are predicted to be below the World Bank criteria outside the mine buffer. Figures 4.2-5 and 4.2-6 present the maximum 24-hour and annual SO₂ predictions, respectively.

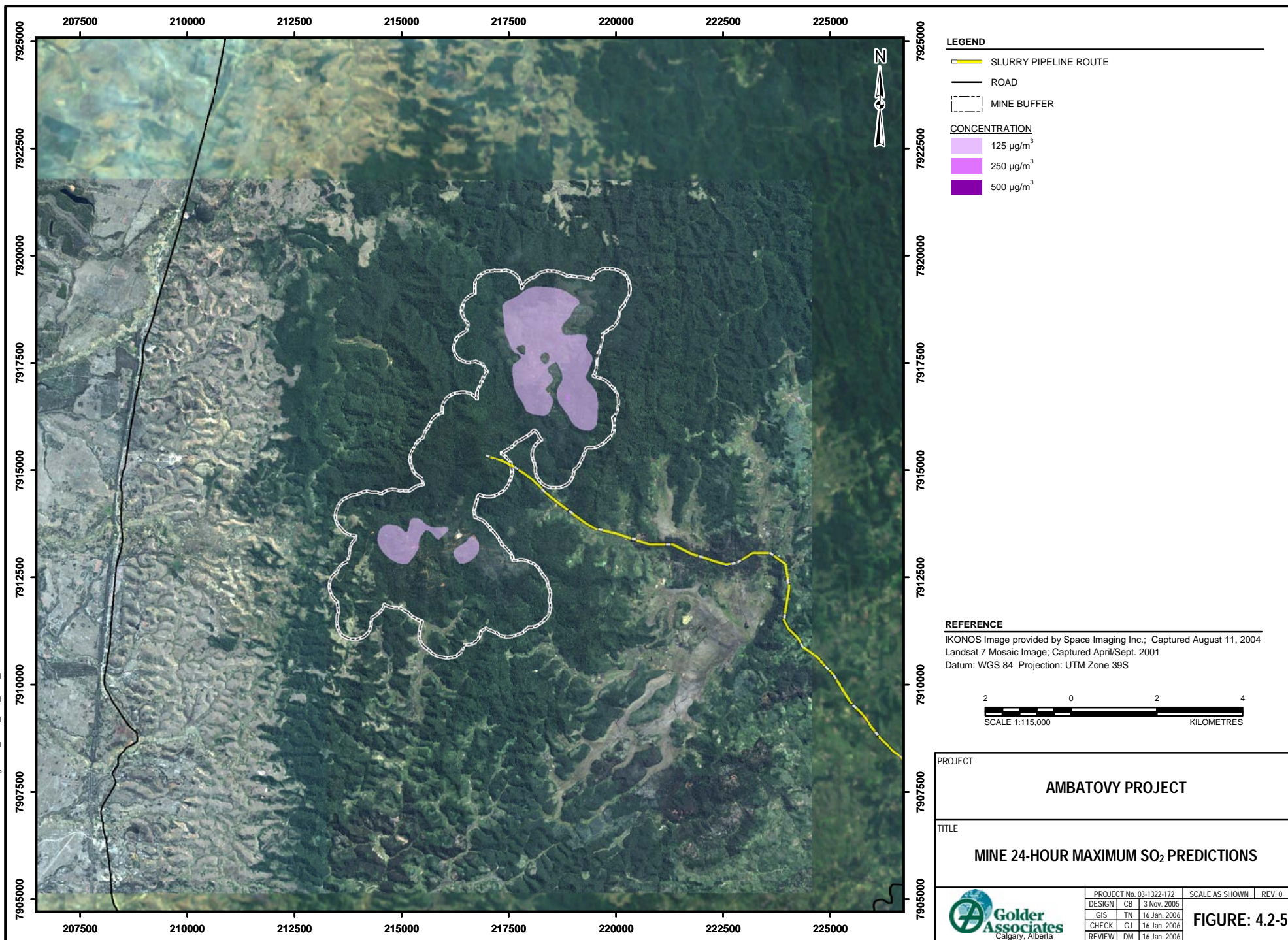
Table 4.2-7 SO₂ Predictions in the Mine Study Area

Parameter	Averaging Period	
	24-hour	Annual
maximum SO ₂ concentration [µg/m ³]	258.3	152.0
maximum SO ₂ concentration outside mine buffer [µg/m ³]	111.2	52.3
distance to maximum concentration [km] ^(a)	5.2	5.2
direction to maximum concentration ^(a)	NNE	NNE
World Bank Open Pit Mining SO₂ Criteria [µg/m³]	500	100

^(a) Distance and direction are from the slurry processing area to the maximum concentration outside the mine buffer.

Table 4.2-8 summarizes the maximum predicted 24-hour and annual SO₂ concentrations at each of the regional communities due to emissions from the mine. The predictions do not include background concentrations of SO₂ from community sources (e.g., vehicle traffic). None of the concentrations exceed the World Bank guidelines for SO₂.

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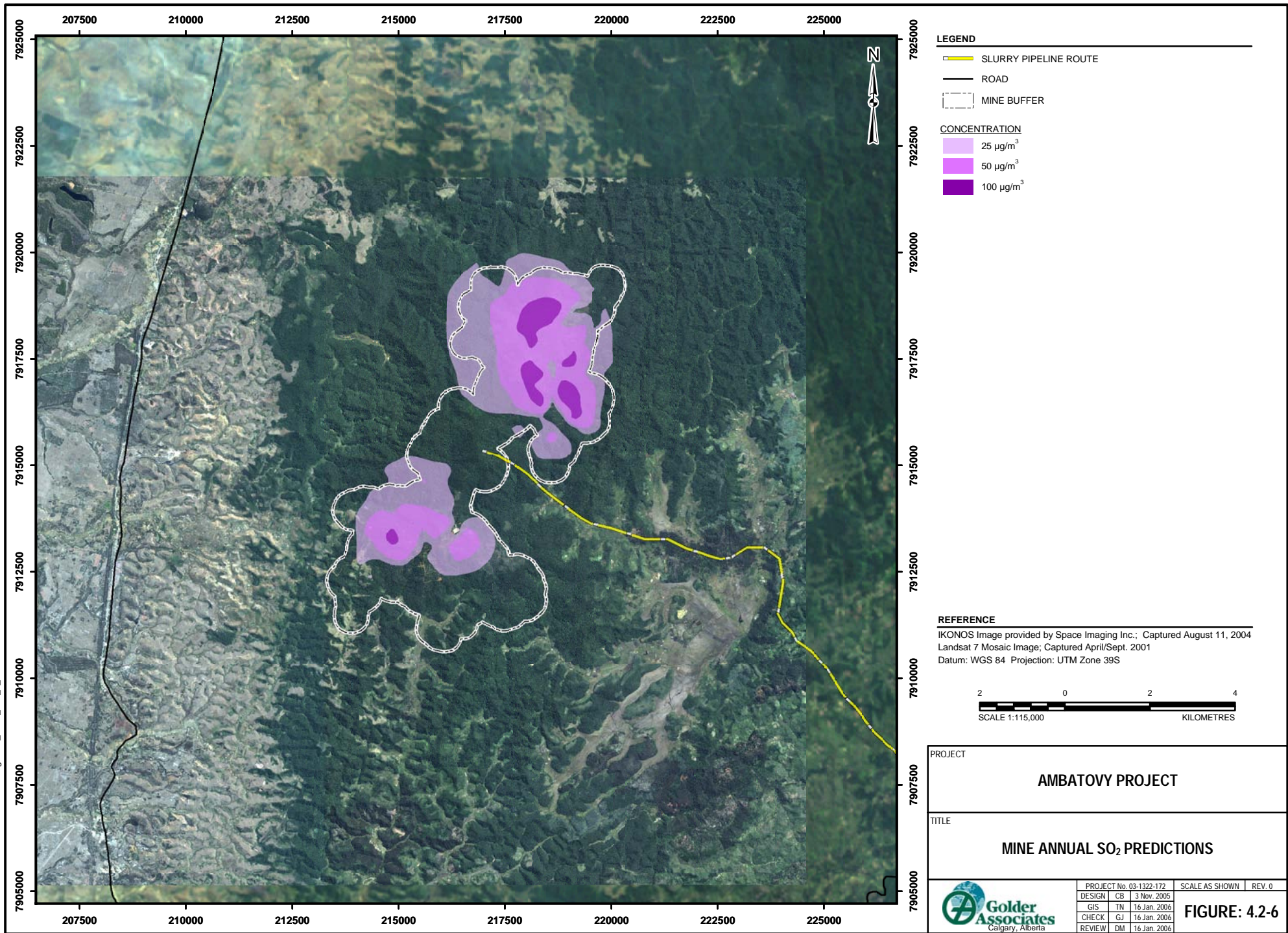


Table 4.2-8 SO₂ Predictions in Regional Communities

Community	Maximum SO ₂ [µg/m ³]	
	24-hour	Annual
Amboditrampanga	1.1	0.1
Ambodivato	0.6	0.1
Ambodivoasary (1)	1.6	0.1
Ambodivoasary (2)	0.4	0.0
Ambohibary	0.5	0.1
Ambohimanarivo	1.6	0.7
Ampitambe	0.9	0.2
Analakely	0.6	0.1
Analalava	0.5	0.1
Andranokoaka	1.0	0.2
Antanambao	1.9	0.4
Antaniditra	1.0	0.1
Antsahapandrano	5.7	1.7
Befotsy	0.6	0.1
Mahamanana	1.6	0.5
Mahatsara	1.9	0.4
Menalamba	0.9	0.1
Nangarana	1.3	0.4
Sahamalotra	1.6	0.2
Sakalava Ambony	5.9	2.6
World Bank Open Pit Mining SO₂ Criteria [µg/m³]	500	100

Note: Predicted community concentrations do not include background values.

3.4.2 Oxides of Nitrogen

Table 4.2-9 presents the maximum NO₂ predictions resulting from activities at the mine. The maximum 24-hour and annual concentrations within the study area are predicted to be below the World Bank criteria. Figures 4.2-7 and 4.2-8 present the maximum 24-hour and annual NO₂ predictions, respectively.

Table 4.2-9 NO_x and NO₂ Predictions in the Mine Study Area

Parameter	Averaging Period	
	24-hour	Annual
maximum NO _x concentration [µg/m ³]	1,144.2	577.6
maximum NO ₂ concentration [µg/m ³]	165.2	117.9
maximum NO ₂ concentration outside mine buffer [µg/m ³]	126.9	85.9
distance to maximum concentration [km] ^(a)	1.0	1.0
direction to maximum concentration ^(a)	WNW	WNW
World Bank Open Pit Mining NO₂ Criteria [µg/m³]	200	100

^(a) Distance and direction are from the slurry processing area to the maximum concentration outside the mine buffer.

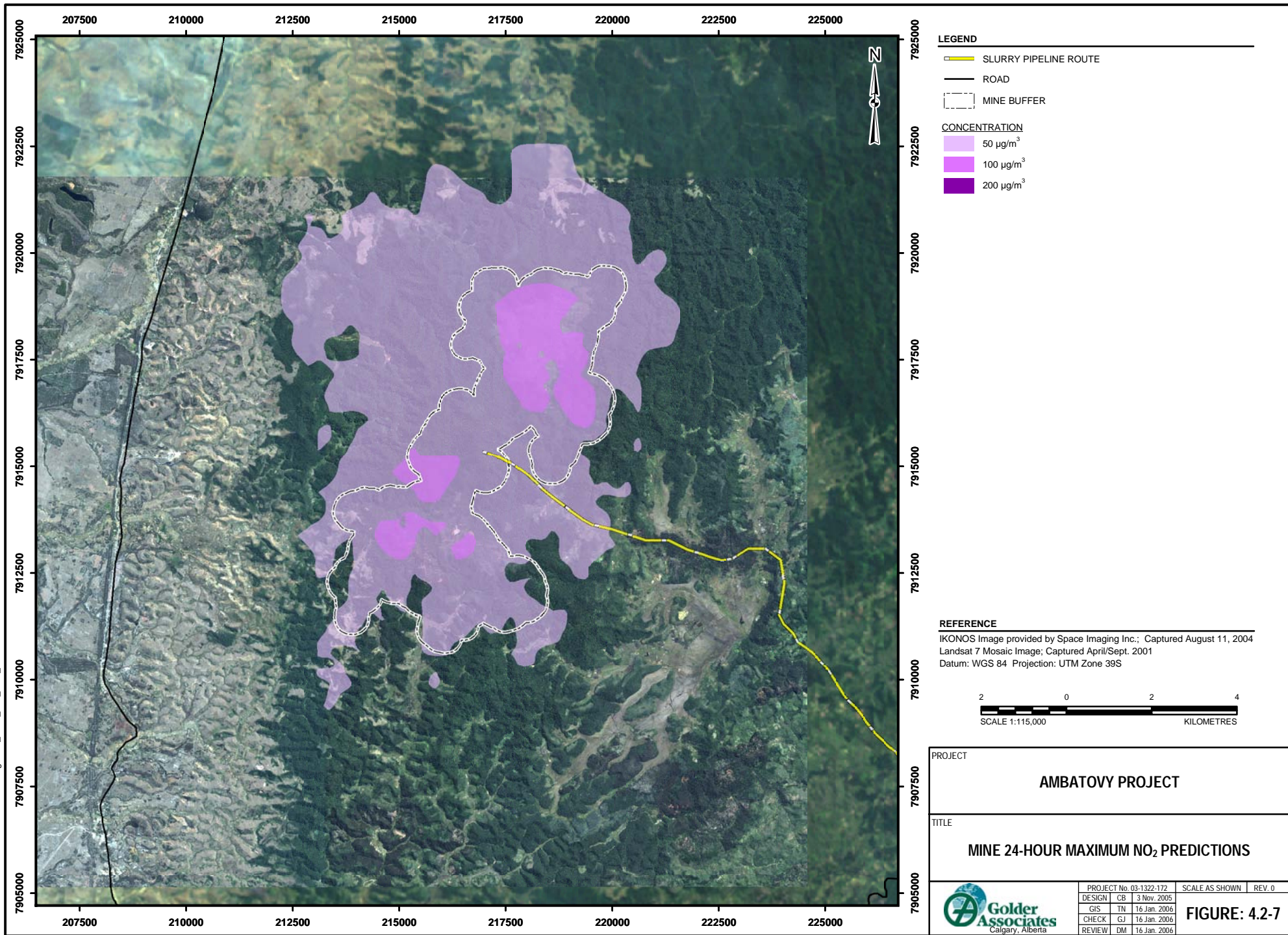
Table 4.2-10 summarizes the maximum predicted 24-hour and annual NO₂ concentrations at each of the regional communities due to emissions from the mine. None of the concentrations exceed the World Bank guidelines for NO₂.

Table 4.2-10 NO₂ Predictions in Regional Communities

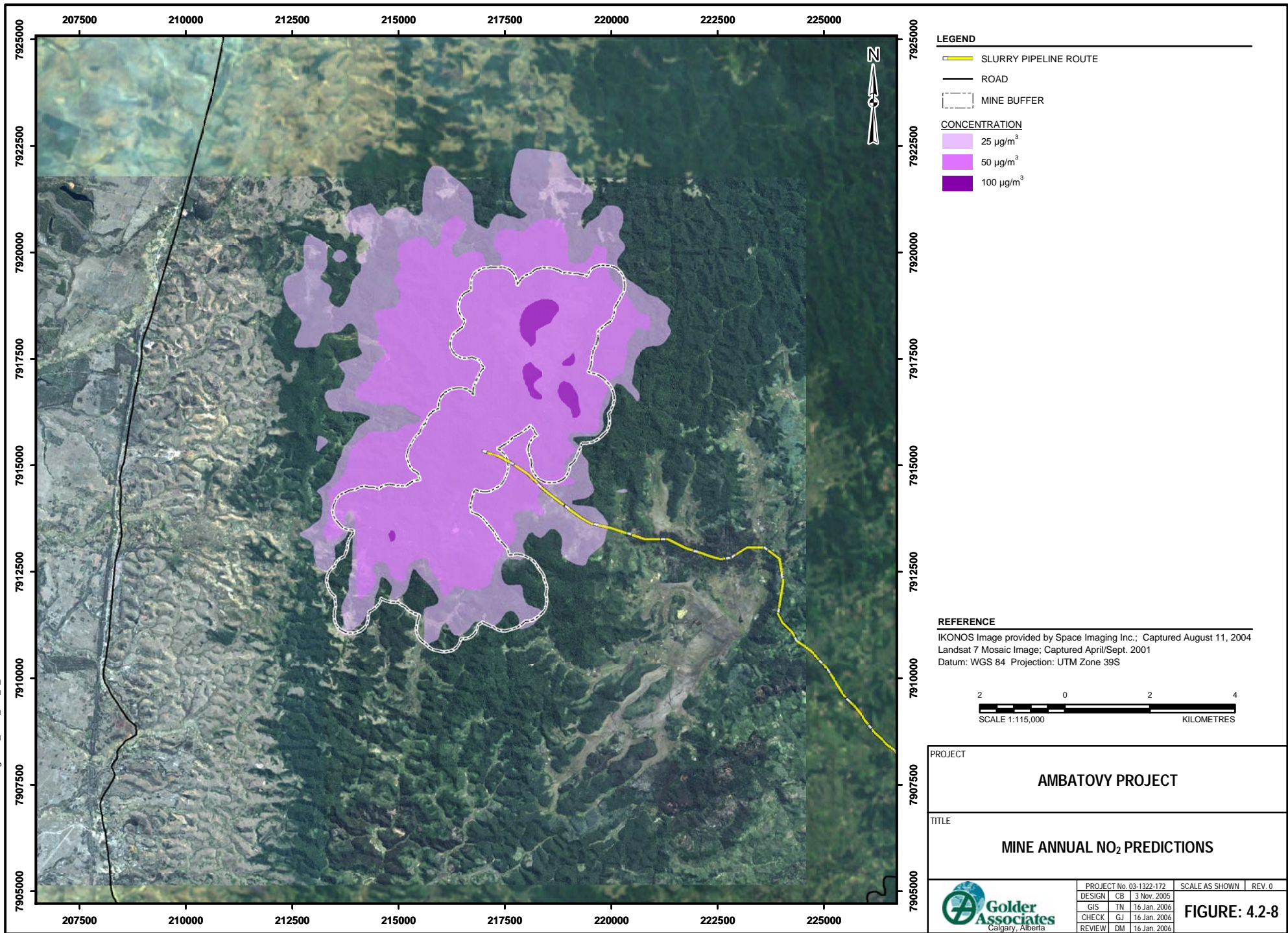
Community	Maximum NO ₂ [µg/m ³]	
	24-hour	Annual
Amboditrampanga	4.1	0.4
Ambodivato	2.2	0.4
Ambodivoasary (1)	8.1	0.4
Ambodivoasary (2)	1.5	0.2
Ambohibary	1.7	0.3
Ambohimanarivo	10.4	3.9
Ampitambe	4.9	0.8
Analakely	2.3	0.3
Analalava	1.7	0.3
Andranokoaka	5.6	1.1
Antanambao	9.4	1.8
Antaniditra	4.2	0.5
Antsahapandrano	23.9	6.6
Befotsy	2.1	0.4
Mahamanana	7.1	1.9
Mahatsara	9.4	1.8
Menalamba	3.6	0.5
Nangarana	5.6	1.5
Sahamalotra	7.0	1.0
Sakalava Ambony	26.5	10.2
World Bank Open Pit Mining NO₂ Criteria [µg/m³]	200	100

Note: Predicted community concentrations do not include background values.

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I:/2003/03-1322/03-1322-172/mxd/Air/Fig4.2-8_mine_no2_a_85x11.mxd



3.4.3 Particulate Matter

Tables 4.2-11 presents the 24-hour and annual particulate matter with diameter less than 10 μm (PM_{10}) and the annual Total Suspended Particulate (TSP) predictions resulting from activities at the mine. The maximum predicted concentrations within the study area are below the World Bank criteria. Figures 4.2-9 through 4.2-11 show the maximum 24-hour and annual PM_{10} as well as the annual TSP predictions, respectively.

Table 4.2-11 Particulate Matter Predictions in the Mine Study area

Parameter	Averaging Period	
	24-hour	annual
maximum PM_{10} concentration [$\mu\text{g}/\text{m}^3$]	127.9	78.9
maximum PM_{10} concentration outside mine buffer [$\mu\text{g}/\text{m}^3$]	53.0	28.0
distance to maximum concentration [km] ^(a)	2.9	2.9
direction to maximum concentration ^(a)	N	N
World Bank Open Pit Mining PM_{10} Criteria [$\mu\text{g}/\text{m}^3$]	500	100
maximum TSP concentration [$\mu\text{g}/\text{m}^3$]	—	220.9
maximum TSP concentration outside mine buffer [$\mu\text{g}/\text{m}^3$]	—	79.4
distance to maximum concentration [km] ^(a)	—	2.9
direction to maximum concentration ^(a)	—	N
World Bank TSP Criteria [$\mu\text{g}/\text{m}^3$]	—	80

^(a) Distance and direction are from the slurry processing area to the maximum concentration outside the mine buffer.

- = No data.

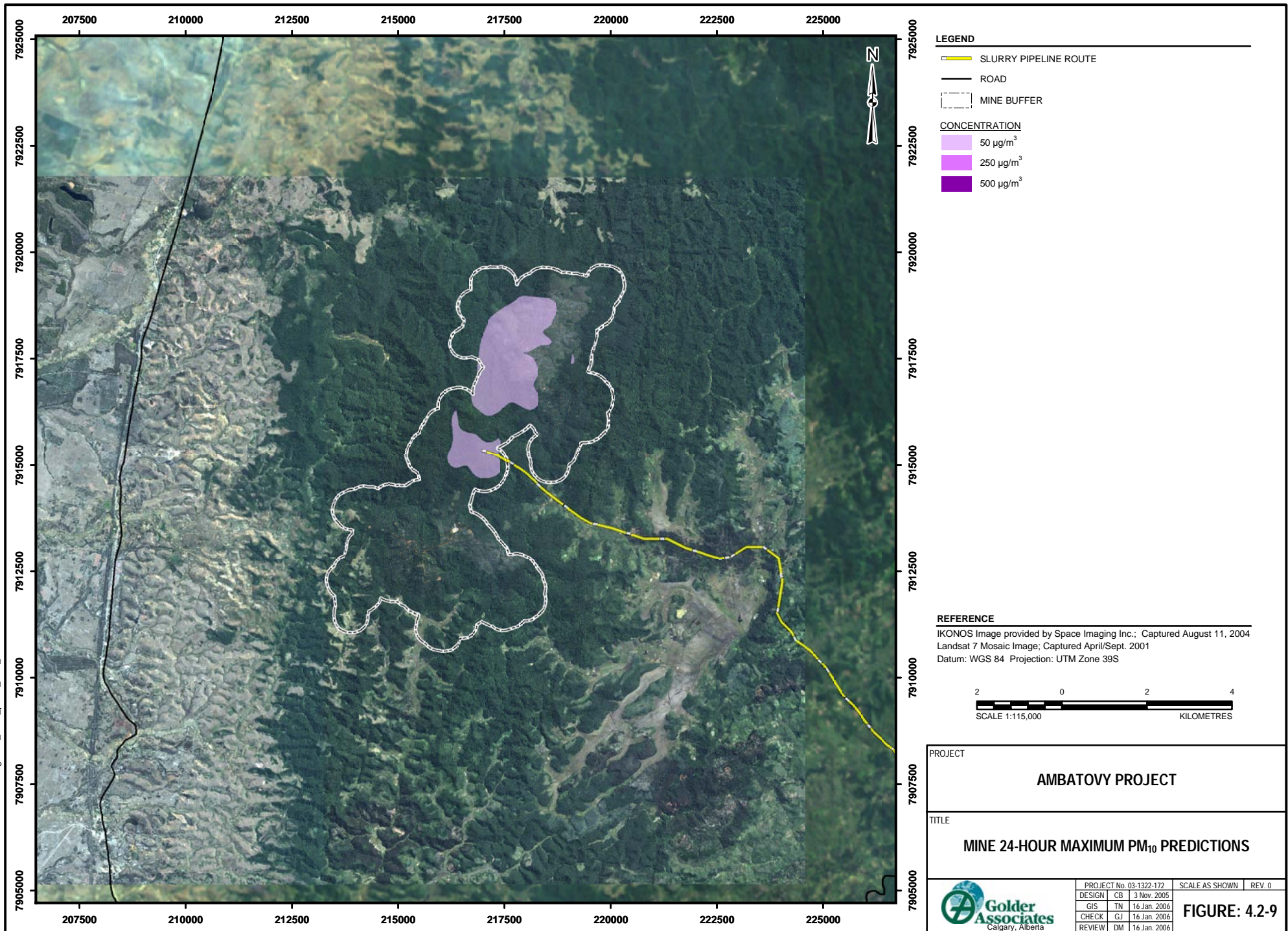
Table 4.2-12 summarizes the maximum predicted 24-hour and annual PM_{10} and annual TSP concentrations at each of the regional communities due to emissions from the mine. These predictions do not include background particulate matter concentrations from community sources (e.g., vehicle traffic). None of the concentrations exceed the World Bank criteria.

Table 4.2-12 Maximum Predicted Particulate Concentrations in Communities

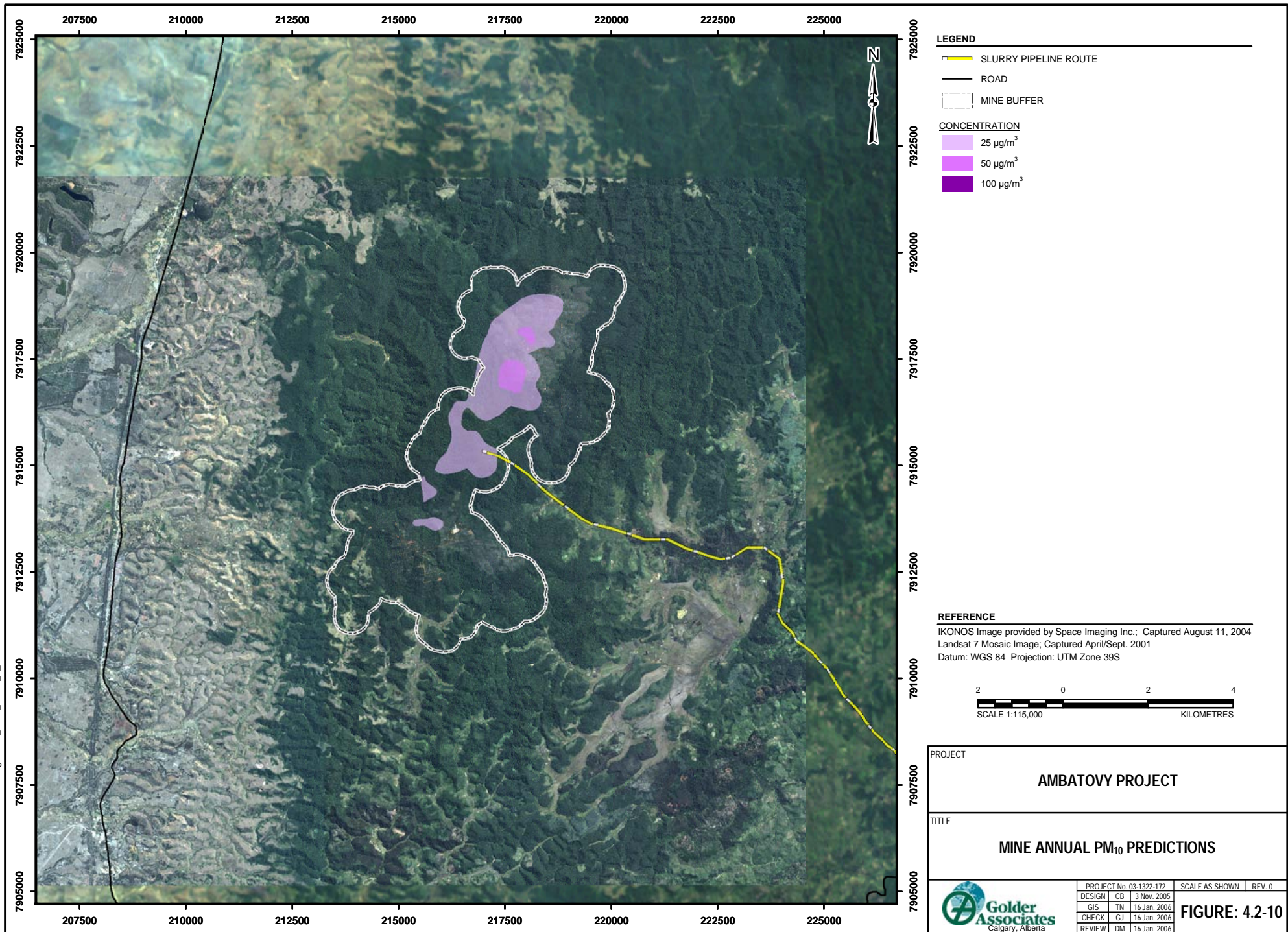
Community	Maximum TSP Concentration [µg/m³]	Maximum PM ₁₀ Concentration [µg/m³]	
	Annual	24-Hour	Annual
Amboditrampanga	0.0	0.4	0.0
Ambodivato	0.0	0.1	0.0
Ambodivoasary (1)	0.0	0.6	0.0
Ambodivoasary (2)	0.0	0.4	0.0
Ambohibary	0.0	0.1	0.0
Ambohimanarivo	0.2	0.6	0.2
Ampitambe	0.0	0.3	0.0
Analakely	0.0	0.5	0.0
Analalava	0.0	0.1	0.0
Andranokoaka	0.0	0.3	0.1
Antanambao	0.1	0.4	0.1
Antaniditra	0.0	0.6	0.0
Antsahapandrano	0.0	0.8	0.1
Befotsy	0.0	0.1	0.0
Mahamanana	0.0	0.4	0.0
Mahatsara	0.0	0.5	0.1
Menalamba	0.0	0.7	0.0
Nangarana	0.0	0.7	0.0
Sahamalotra	0.1	0.9	0.1
Sakalava Ambony	0.4	1.8	0.3
World Bank Criteria [µg/m³]	80	500	100

Note: Predicted community concentrations do not include background values.

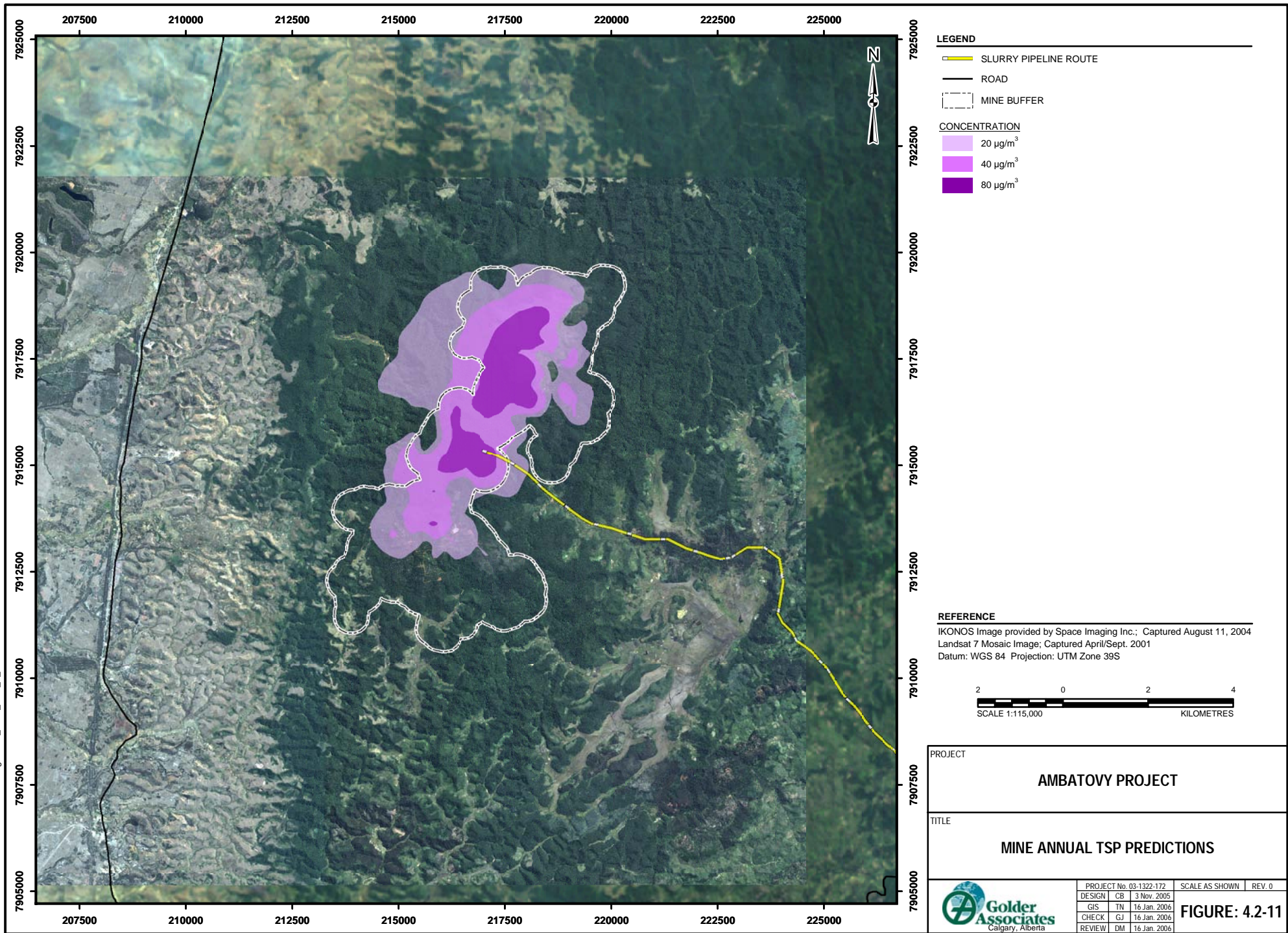
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I:/2003/03-1322/03-1322-172/mxd/Air/Fig4.2-10_mine_PM10_a_85x11.mxd



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3.4.4 Other Compounds

Table 4.2-13 summarizes the maximum predicted annual lead and mercury concentrations at each of the regional communities due to emissions from the mine. The predictions were scaled off of particulate predictions based on the metal content of the ore (from Dynatec analyses) and the diesel fuel (USEPA 1995). The predictions do not include background concentrations from community sources (e.g., vehicle traffic). None of the concentrations exceed the WHO criteria.

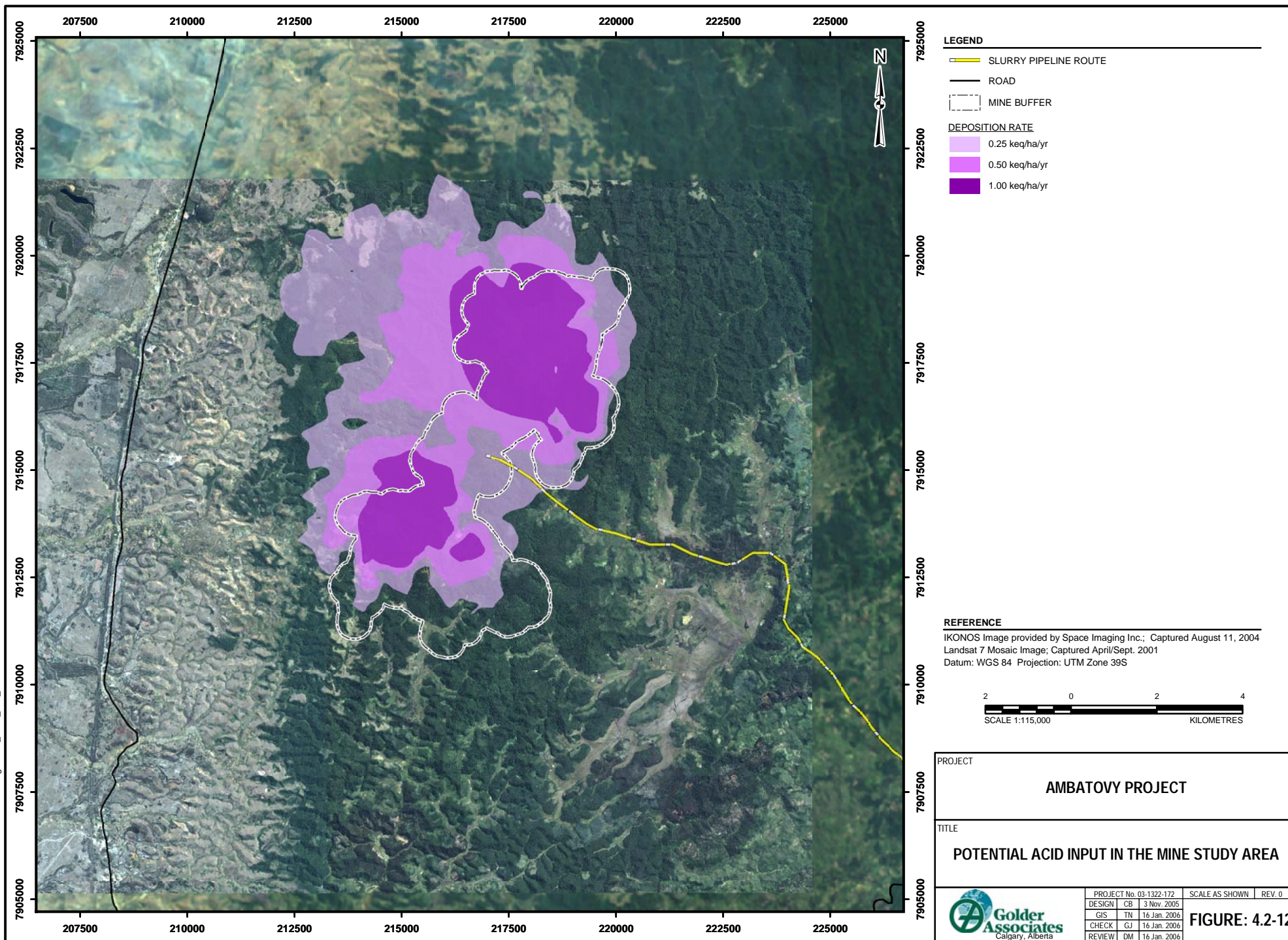
Table 4.2-13 Maximum Predicted Lead and Mercury Concentrations in Communities

Community	Maximum Annual Concentration [$\mu\text{g}/\text{m}^3$]	
	Lead	Mercury
Amboditrampanga	0.0000065	0.0000003
Ambodivato	0.0000064	0.0000003
Ambodivoasary (1)	0.0000061	0.0000003
Ambodivoasary (2)	0.0000037	0.0000002
Ambohibary	0.0000046	0.0000003
Ambohimananarivo	0.0000481	0.0000029
Ampitambe	0.0000103	0.0000005
Analakely	0.0000055	0.0000002
Analalava	0.0000049	0.0000003
Andranokoaka	0.0000134	0.0000007
Antanambao	0.0000202	0.0000010
Antaniditra	0.0000076	0.0000003
Antsahapandrano	0.0000411	0.0000004
Befotsy	0.0000060	0.0000003
Mahamanana	0.0000171	0.0000004
Mahatsara	0.0000199	0.0000009
Menalamba	0.0000081	0.0000003
Nangarana	0.0000132	0.0000002
Sahamalotra	0.0000129	0.0000006
Sakalava Ambony	0.0000708	0.0000008
WHO Criteria [$\mu\text{g}/\text{m}^3$]	0.5	1

Notes: Predicted community concentrations do not include background values.

3.4.5 Acid Deposition

Potential acid input (PAI) is a method for evaluating the overall effects of acid-forming compounds on the environment since it accounts for the acidifying effect of the sulphur and nitrogen species, as well as the neutralizing effect of available base cations. Figure 4.2-12 shows the contours of acid deposition in the mine study area.



4 PROCESS PLANT

4.1 RECEPTORS

Ground-level concentrations and deposition rates were modelled at selected locations within the modelling domain. These locations (referred to as receptors) were distributed as follows:

- spacing of 50 m within 0.5 km of the sources of interest;
- spacing of 250 m within 2 km of the sources of interest;
- spacing of 500 m within 5 km of the sources of interest; and
- spacing of 1 km within 10 km of the sources of interest.

Also included were 500 m spaced receptors covering 7 km by 5 km centred on the tailings facility. In total, 1,670 receptors were included in the modelling.

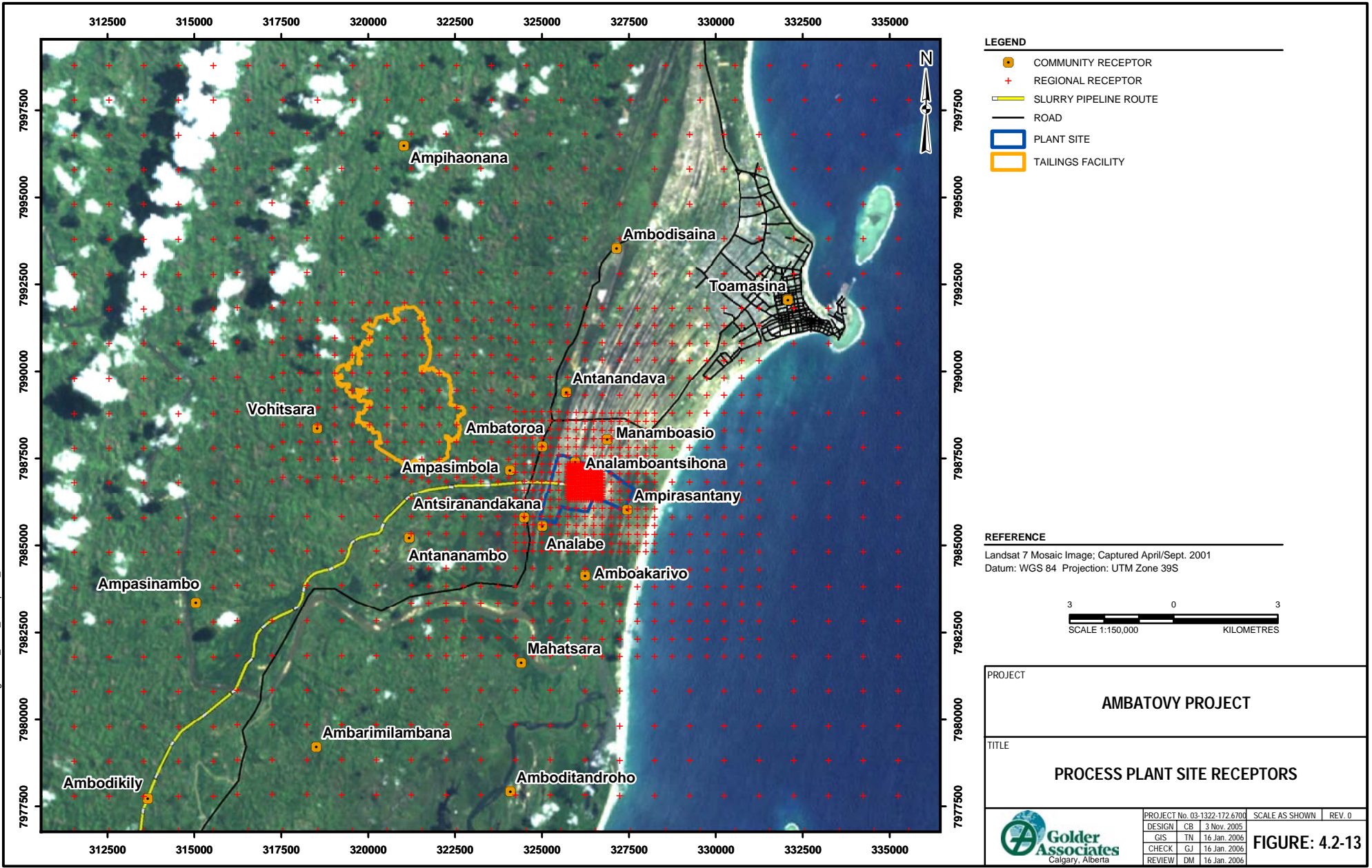
Additional receptors were also placed at selected communities in the region (Table 4.2-14). The modelled receptors are shown graphically in Figure 4.2-13.

Table 4.2-14 Process Plant Site Community Receptors

Community	Distance [km]	Direction
Ambarimilambana	10.9	SW
Ambatoroa	1.6	NW
Amboakarivo	2.7	S
Ambodikily	15.5	SW
Ambodisaina	6.8	N
Amboditandroho	9.2	SSW
Ampasimbola	2.2	W
Ampasinambo	11.7	WSW
Ampihaonana	11.0	NNW
Ampirasantany	1.5	SE
Analabe	1.8	SW
Antananambo	5.3	WSW
Antanandava	2.6	NNW
Antsiranandakana	2.0	WSW
Mahatsara	5.5	SSW
Manamboasio	1.4	NNE
Toamasina	7.8	NE
Vohitsara	7.9	W

Note: Distance and direction relative to centre of process plant.

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4.2 DISPERSION METEOROLOGY

The weather in the process plant site region is dominated by frequent cyclone activity and easterly trade winds. The northeastern coast of Madagascar receives regular rainfall throughout the year due to the predominant easterly and southeasterly winds being lifted by the mountain ridge in to the west. Three years of meteorological data from Toamasina were used in the modelling (2001 to 2003).

4.2.1.1 Temperature, Precipitation and Relative Humidity

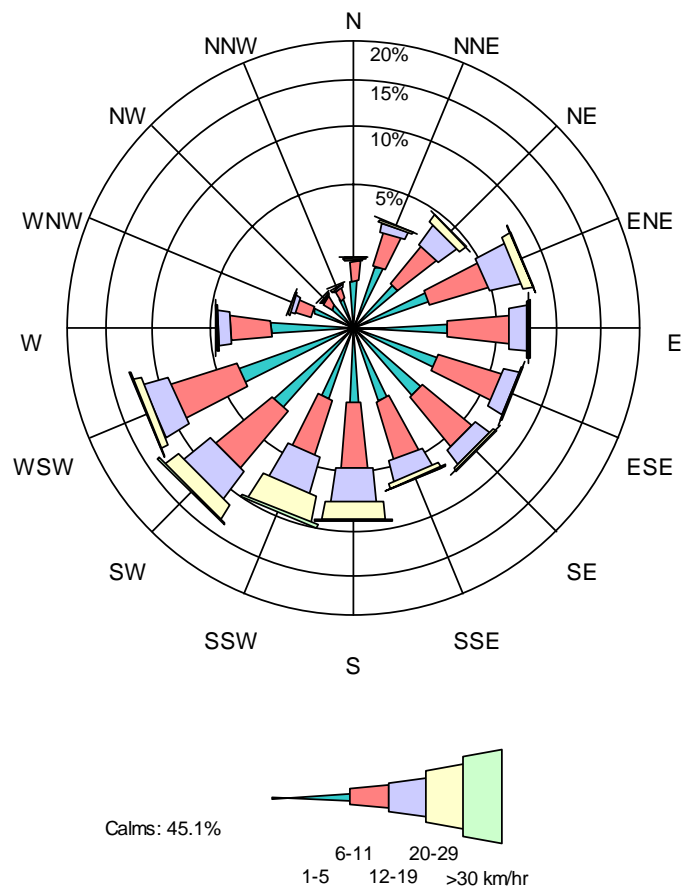
Based on three years of data (2001 to 2003), hourly temperatures at Toamasina ranged from 13.9°C in July 2001 to 35.6°C in January 2002 with an annual average temperature of 24°C.

Toamasina receives rain year-round. The annual average rainfall is over 3,000 mm. The annual average humidity is 84% with a minimum value of 40%.

4.2.1.2 Wind Speed and Direction

Figure 4.2-14 shows a windrose of data collected at Toamasina from 2001 to 2003. The predominant wind directions are from the south to the west-southwest sector. The average annual wind speed is 6 km/hr with maximum hourly speeds over 60 km/hr. One significant aspect of the winds at Toamasina is the high frequency of calm conditions (45.1%). There is a definite diurnal pattern in the winds where calm conditions (less than 3 km/hr) typically occur at night. The Toamasina station location and data were verified by the station chief and the Direction de la Météorologie (Haja pers. comm.. 2005).

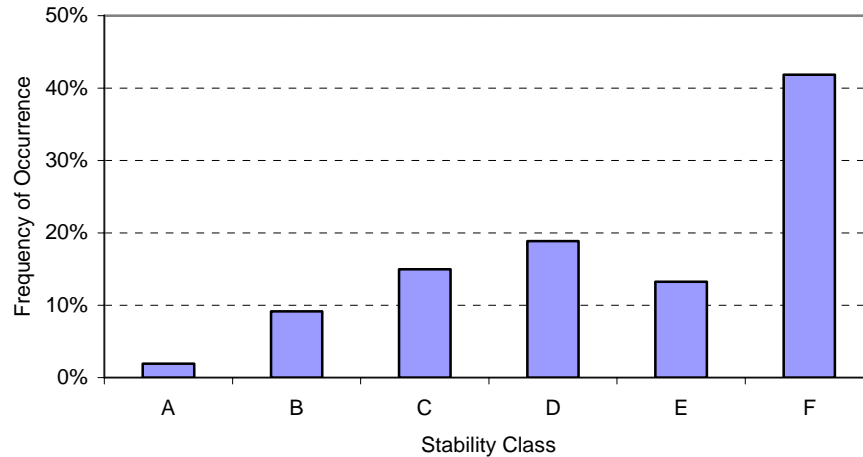
Figure 4.2-14 Toamasina Windrose (2001 to 2003)



4.2.1.3 Atmospheric Stability

The preferred method for calculating atmospheric Pasquill Gifford (PG) stability classes is the Turner method (Turner 1964). This method uses cloud cover, ceiling height and wind speed data measured at the Toamasina station for 2001 to 2003. Figure 4.2-15 provides a histogram showing the frequency of the derived PG stability classes. During these years of observed meteorological data, unstable conditions occurred about 26% of the time, neutral conditions occurred 19% of the time, and stable conditions accounted for the remaining 55% of the observations.

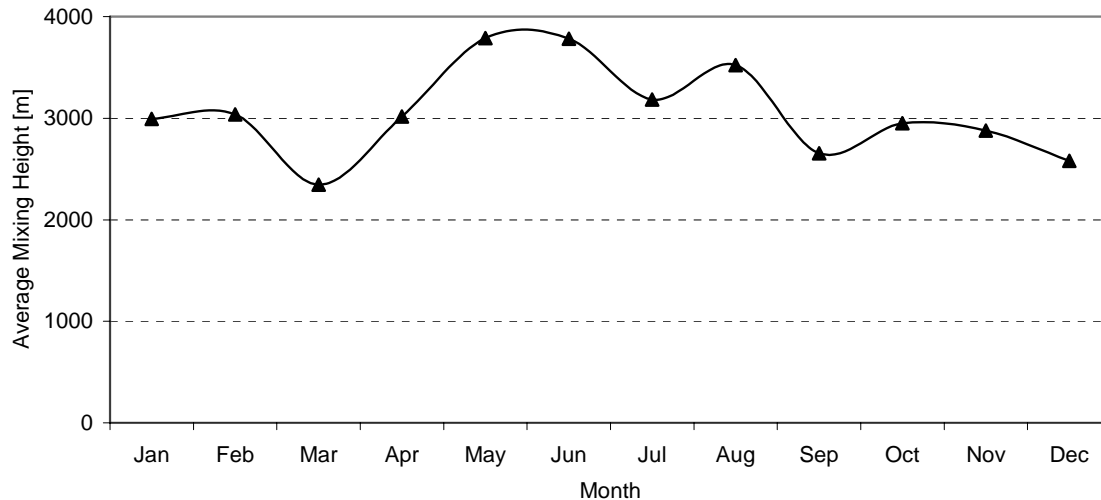
Figure 4.2-15 Frequency of Pasquill-Gifford Stability Conditions at Toamasina (2001 to 2003)



4.2.1.4 Mixing Heights

A monthly summary of calculated mixing heights at Toamasina for stability classes A to D is provided in Figure 4.2-16. Mixing heights were set to unlimited for stable conditions (E and F). The lowest average mixing height of about 2,300 m above ground occurs in March, while the highest average of about 3,900 m above ground occurs in May. These values are representative of the equatorial region where strong heating results in significant vertical mixing which can result in very large mixing heights. Emissions from the process plant are not likely to reach these heights since other factors such as stack exit velocity and temperature will play a more significant role in the dispersion of these emissions.

Figure 4.2-16 Monthly Average Mixing Heights at Toamasina (2001 to 2003)



4.3 EMISSIONS

This section provides a summary of the air emissions information used in the air quality assessment of the process plant. The objective of this section is to identify and document the basis for the emissions information used in the air quality assessment.

The activities at the process plant will result in the release of emissions of SO₂, NO_x, particulate matter and H₂S to the atmosphere. The emissions during normal maximum production (without the refinery) were provided by Dynatec. Sulphur dioxide emissions from the flares and fugitive particulate emissions from the coal and limestone stockpiles were derived by Golder Associates. Flare emissions for normal operations were assumed to be continuous. Sulphur dioxide emissions were calculated based on the gas composition and volumetric flow rate provided by Dynatec. Two other flaring scenarios – maintenance and emergency flaring – were modelled and the results are presented in Section 4.6.

During periods with high wind speeds, it is possible for dust to be eroded from exposed areas of the process plant, specifically stockpiles. While the emissions due to these events can be calculated accurately, it is difficult to accurately model the releases. The CALPUFF dispersion model allows the user to input a threshold wind velocity, below which the emissions of wind blown dust will not occur. In assessing the particulate releases from the stockpiles, it was determined that wind erosion of the exposed areas would occur when the wind speeds

exceeded 5.3 m/s. Such wind speeds were observed to occur at the process plant site 1,251 hours during the year.

Table 4.2-15 presents detailed information regarding the emission factors, project base quantities, and emission controls used to estimate emissions from the process plant. Table 4.2-16 provides a summary of the process plant emission rates used in the air quality assessment.

Table 4.2-15 Summary of Process Plant Emission Information

Activity	Information Used
Leach	
emission factors	SO ₂ , NO _x , TSP, H ₂ S, CO ₂ , and CH ₄ emissions provided in the June 20, 2005 e-mail SO ₂ and H ₂ S emissions for the sulphide area flare calculated based on flared gas composition and volumetric rate provided in the June 20, 2005 e-mail N ₂ O emissions assumed to be 0.1% of NO _x emissions as provided in the October 19, 2005 e-mail Odour units calculated based on H ₂ S odour threshold of 7.00 µg/m ³ (WHO 30-min guideline value)
base quantities	Sulphide area flare pilot flame flow rate of 82.2 scf/h and gas composition of 0.568 mol C ₃ H ₆ , 0.431 mol C ₄ H ₁₀ , 0.0008 mol H ₂ S as provided in the June 20, 2005 e-mail Sulphide area flare continuous purge flow rate of 4,670 scf/h and gas composition of 0.005 mol H ₂ S and 0.995 mol N ₂ as provided in the June 20, 2005 e-mail
emission controls	no emission controls assumed
Utilities	
emission factors	SO ₂ , NO _x , TSP, H ₂ S, CO ₂ , and CH ₄ emissions provided in the June 20, 2005 e-mail SO ₂ and H ₂ S emissions for the hydrogen sulphide flare calculated based on flared gas composition and volumetric rate provided in the June 20, 2005 e-mail N ₂ O emissions assumed to be 0.1% of NO _x emissions as provided in the October 19, 2005 e-mail PAH emissions for the coal-fired boilers based on PAH emission factors from Table 4.1.2-10 of <u>Locating and Estimating Air Emissions from Sources of Polycyclic Organic Matter</u> (EPA-454/R-98-014) (USEPA 1998) Odour units calculated based on H ₂ S odour threshold of 7.00 µg/m ³ (WHO 30-min guideline value)
base quantities	Hydrogen sulphide flare pilot flame flow rate of 123.3 scf/h and gas composition of 0.568 mol C ₃ H ₆ , 0.431 mol C ₄ H ₁₀ , 0.0008 mol H ₂ S as provided in the June 20, 2005 e-mail Hydrogen sulphide flare continuous purge flow rate of 11,208 scf/h and gas composition of 0.005 mol H ₂ S and 0.995 mol N ₂ as provided in the June 20, 2005 e-mail Coal consumption of 18 t/h-per boiler as provided in the August 11, 2005 e-mail
emission controls	no emission controls assumed
Coal Stockpile	
emission factors	wind erosion TSP emission factor of 723 g/m ² -yr calculated based on §13.2.5 of USEPA AP-42 (USEPA 1995) wind erosion PM ₁₀ emission factor of 362 g/m ² -yr calculated based on §13.2.5 of USEPA AP-42 (USEPA 1995) wind erosion PM _{2.5} emission factor of 145 g/m ² -yr calculated based on §13.2.5 of USEPA AP-42 (USEPA 1995)

Table 4.2-15 Summary of Process Plant Emission Information (continued)

Activity	Information Used
base quantities	stockpile area of 8,751 m ² determined based on plot plan stockpile disturbance interval of 720 min calculated based on the assumption of 2 disturbances/d anemometer height of 5 m based on Toamasina meteorological station roughness height of 10 cm assumed threshold friction velocity of 0.54 m/s from Table 13.2.5-2, §13.2.5, of USEPA AP-42 (USEPA 1995) hourly friction velocities calculated based on Toamasina meteorological data and Equation 1, §13.2.5, of USEPA AP-42 (USEPA 1995) hourly erosion potentials calculated based on Equation 3, §13.2.5, of USEPA AP-42 (USEPA 1995)
emission controls	no emission controls assumed
Limestone Stockpile	
emission factors	wind erosion TSP emission factor of 723 g/m ² ·yr calculated based on §13.2.5 of USEPA AP-42 (USEPA 1995) wind erosion PM ₁₀ emission factor of 362 g/m ² ·yr calculated based on §13.2.5 of USEPA AP-42 (USEPA 1995) wind erosion PM _{2.5} emission factor of 145 g/m ² ·yr calculated based on §13.2.5 of USEPA AP-42 (USEPA 1995)
base quantities	stockpile area of 9,361 m ² determined based on plot plan stockpile disturbance interval of 720 min calculated based on the assumption of 2 disturbances/d anemometer height of 5 m based on Toamasina meteorological station roughness height of 10 cm assumed threshold friction velocity of 0.54 m/s from Table 13.2.5-2, §13.2.5, of USEPA AP-42 (USEPA 1995) hourly friction velocities calculated based on Toamasina meteorological data and Equation 1, §13.2.5, of USEPA AP-42 (USEPA 1995) hourly erosion potentials calculated based on Equation 3, §13.2.5, of USEPA AP-42 (USEPA 1995)
emission controls	no emission controls assumed

4.3.1 Source Inputs

One of the most important factors in a dispersion modelling evaluation is the source input characteristics used to simulate the ground-level concentrations. Tables 4.2-17 and 4.2-18 present the source characteristics for the point and area sources modelled, respectively, in the air quality assessment of the process plant.

Table 4.2-16 Process Plant Air Emissions Summary

Source	Emission Rate [t/d]				
	SO ₂	NO _x	PM ₁₀	TSP	H ₂ S
leach - liquor neutralization tank (combined)	—	—	—	—	0.239
leach - sulphide area flare	0.042	0.000	—	—	0.000
leach - vent scrubber	—	—	—	—	0.001
utilities - hydrogen plant (combined)	0.058	0.084	—	—	—
utilities - hydrogen sulphide flare stack	0.101	0.000	—	—	0.001
utilities - sulphur melting, neutralization and filtration	0.005	—	—	—	—
utilities - acid plant	6.048	—	—	—	—
utilities - limestone crushing	—	—	0.006	0.006	—
utilities - limestone calcining	1.342	0.720	0.048	0.048	—
utilities - lime slaking	—	—	0.001	0.001	—
utilities – coal-fired boilers	8.194	4.421	0.370	0.370	—
coal stockpile	—	—	0.009	0.017	—
limestone stockpile	—	—	0.009	0.019	—
Total^(a)	15.789	5.225	0.443	0.460	0.242

“—” indicates no emissions from this source.

^(a) Some numbers are rounded for presentation purposes. Therefore, it may appear that the totals do not equal the sum of the individual values.

4.4 AIR QUALITY PREDICTIONS

The expected emissions of SO₂, NO_x, TSP, PM₁₀ and H₂S from the operation of the process plant were input into the CALPUFF dispersion model to determine ground-level concentrations within the study area. The CALPUFF model was run in the steady-state (2-D) mode using three years of meteorological observations collected at the Toamasina Airport. A listing of dispersion modelling source inputs is presented in Section 4.3.1.

The results of the modelling are presented in the following sections. All modelling results have been presented for the study area except the plant site itself.

Table 4.2-17 Process Plant Point Source Emission Characteristics

Source Name	Source Description	Easting (m)	Northing (m)	Base Elevation (m)	Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/s)	Exit Temperature (K)
DYPLNTSVNT01	leach - vent scrubber	326,455	7,986,733	7.4	30.00	0.200	22.6	338
DYPLNTSVNT02	leach - vent scrubber	326,418	7,986,669	7.3	30.00	0.200	22.6	338
DYPLNTSVNT03	leach - vent scrubber	326,381	7,986,604	7.2	30.00	0.200	11.3	338
DYPLNTSNTK	leach - slurry neutralization tank (combined)	326,235	7,986,466	8.4	17.00	1.500	10.3	362
DYPLNTBNTK	leach - barren liquor neutralization tank (combined)	326,083	7,986,549	7.1	15.00	0.600	22.4	365
DYPLNTTNTK	leach - tailings neutralization tank (combined)	326,009	7,986,567	6.5	15.00	0.500	25.9	349
DYPLNTRHTR	leach - raw liquor heater (combined)	326,400	7,986,750	7.6	40.00	0.200	24.9	368
DYPLNTLNTK	leach - liquor neutralization tank (combined)	326,381	7,986,761	7.7	21.00	1.000	18.0	359
DYPLNTPHTR01	leach - sulphide precipitation preheater	326,286	7,986,702	7.4	30.00	0.300	5.9	368
DYPLNTPHTR02	leach - sulphide precipitation preheater	326,296	7,986,670	7.3	30.00	0.300	5.9	368
DYPLNTSAFL	leach - sulphide area flare	326,253	7,986,670	7.3	40.46	0.547	0.8	1,273
DYPLNTSVNT04	leach - vent scrubber	326,320	7,986,688	7.3	12.00	0.250	12.9	323
DYPLNTHPLT01	utilities - hydrogen plant (combined)	325,966	7,986,920	8.2	50.00	0.800	15.3	428
DYPLNTHPLT02	utilities - hydrogen plant (h ₂ vent)	325,975	7,986,914	8.1	30.00	0.200	55.0	303
DYPLNTHSFL	utilities - hydrogen sulphide flare stack	326,669	7,986,828	5.9	40.57	0.530	1.3	1,273
DYPLNTSMNF	utilities - sulphur melting, neutralization and filtration	326,638	7,986,902	6.0	20.00	0.150	16.1	373
DYPLNTAPLT01	utilities - acid plant	326,566	7,986,844	7.1	60.00	2.900	13.8	353
DYPLNTAPLT02	utilities - acid plant	326,575	7,986,839	7.0	60.00	2.900	13.8	353
DYPLNTLSCR	utilities - limestone crushing	326,299	7,987,058	7.0	20.00	0.350	26.5	313
DYPLNTLSCA	utilities - limestone calcining	326,310	7,987,052	7.1	30.00	1.500	23.2	511
DYPLNTLSSL	utilities - lime slaking	326,319	7,987,046	7.1	20.00	0.200	21.6	313
DYPLNTBOLR01	utilities – coal-fired boiler	326,390	7,986,882	7.6	80.00	1.300	48.6	413
DYPLNTBOLR02	utilities – coal-fired boiler	326,402	7,986,904	7.5	80.00	1.300	48.6	413

Table 4.2-18 Process Plant Area Source Emission Characteristics

Source Name	Source Description	Centre Easting (m)	Centre Northing (m)	Source Area (m ²)	Base Elevation (m)	Initial σ_z (m)
DYPLNTCOSP	coal stockpile	326,375	7,987,079	8,751	7.2	4.0
DYPLNTLSSP	limestone stockpile	326,119	7,987,182	9,361	6.9	4.0

4.4.1 Sulphur Dioxide

Table 4.2-19 presents the maximum SO₂ predictions resulting from activities at the processing plant site. Based on the modelling, the maximum 24-hour and annual concentrations are predicted to be below the relevant air quality guidelines. Figures 4.2-17 and 4.2-18 present the maximum 24-hour and annual SO₂ predictions, respectively.

Table 4.2-19 SO₂ Predictions in the Process Plant Study Area

Parameter	Averaging Period	
	24-hour	Annual
maximum SO ₂ concentration [µg/m ³]	69.0	7.9
maximum SO ₂ concentration outside property boundary [µg/m ³]	68.4	7.8
distance to maximum concentration [km](a)	1.0	1.0
direction to maximum concentration(a)	WNW	W
World Bank SO₂ Criteria [µg/m³]	150	80

(a) Distance and direction are from the centre of the process plant to the maximum concentration outside the property boundary.

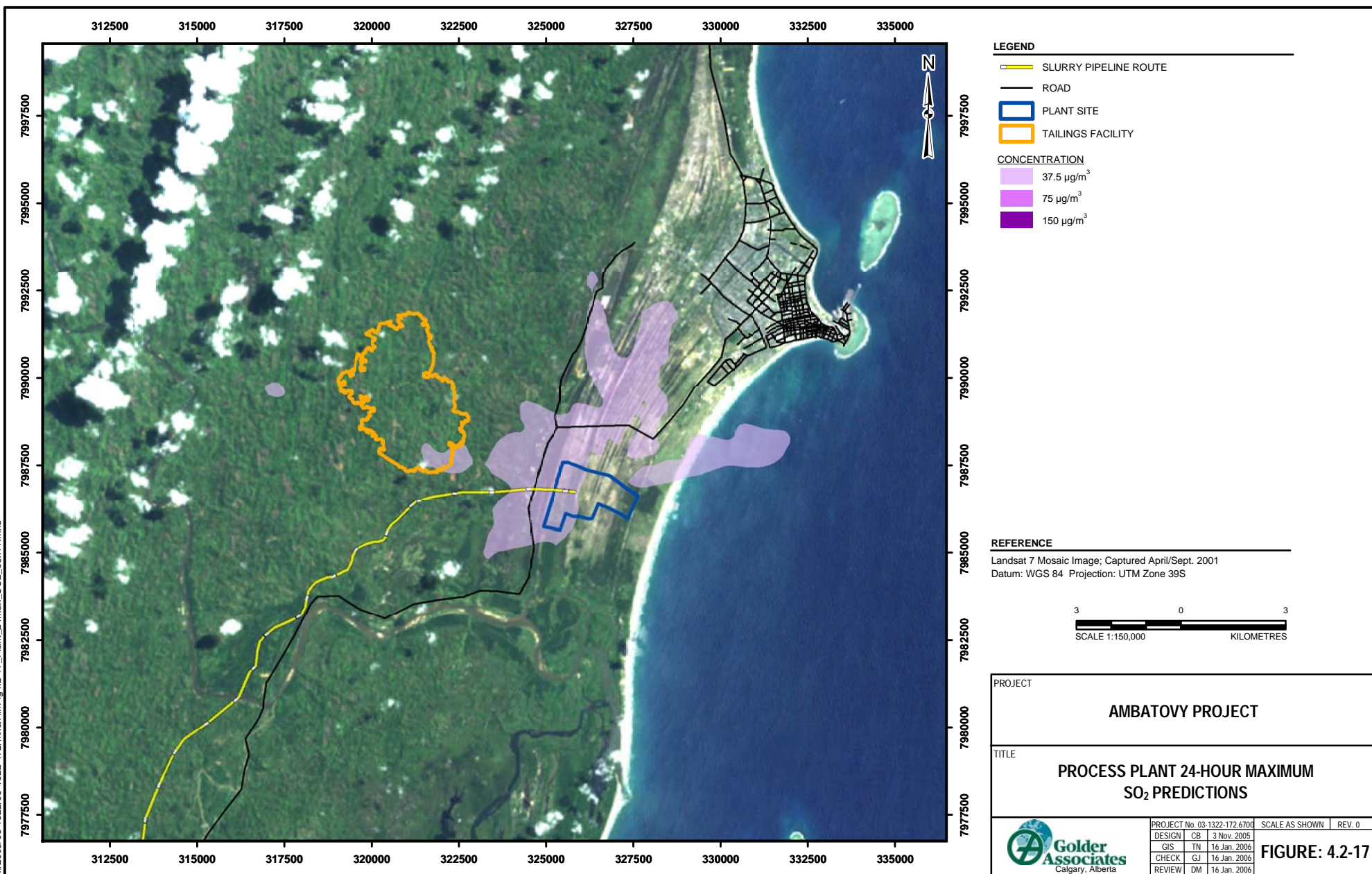
Table 4.2-20 summarizes the maximum predicted 24-hour and annual SO₂ concentrations at each of the regional communities due to emissions from the process plant. These predictions do not include background concentrations of SO₂ from community sources (e.g., vehicle traffic). None of these concentrations exceed the World Bank guidelines for SO₂.

Table 4.2-20 Maximum Predicted SO₂ Concentrations in Communities

Community	Maximum SO ₂ Concentration [µg/m ³]	
	24-Hour	Annual
Ambarimilambana	14.1	1.2
Ambatoroa	54.6	5.7
Amboakarivo	31.2	1.5
Ambodikily	12.7	1.1
Ambodisaina	26.3	2.8
Amboditandroho	19.3	1.0
Ampasimbola	43.1	4.9
Ampasinambo	11.5	1.3
Ampihaonana	9.9	1.4
Ampirasantany	13.7	1.3
Analabe	39.9	4.0
Antananambo	23.1	2.9
Antanandava	32.6	3.7
Antsiranandakana	48.8	5.7
Mahatsara	30.3	1.5
Manamboasio	37.6	5.1
Toamasina	21.9	3.0
Vohitsara	28.1	1.8
World Bank SO₂ Criteria [µg/m³]	150	80

Note: Predicted community concentrations do not include background values.

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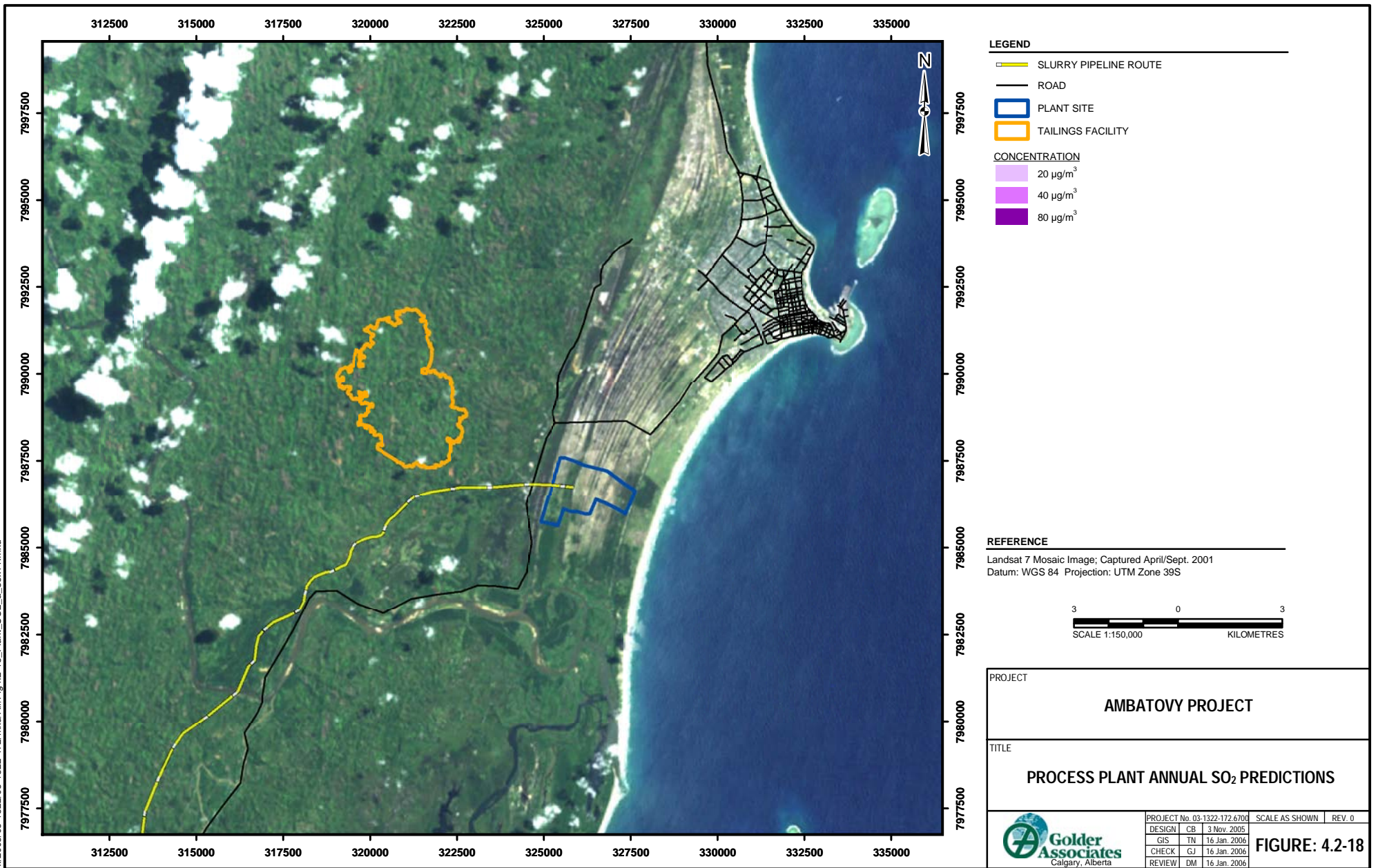


Table 4.2-21 NO_x and NO₂ Predictions in the Process Plant Study Area

Parameter	Averaging Period	
	24-hour	annual
maximum NO _x concentration [µg/m ³]	20.3	2.3
maximum NO ₂ concentration [µg/m ³]	20.3	2.3
maximum NO ₂ concentration outside property boundary [µg/m ³]	20.3	2.3
distance to maximum concentration [km] ^(a)	1.3	1.0
direction to maximum concentration ^(a)	WSW	W
World Bank NO₂ Criteria [µg/m³]	150	100

^(a) Distance and direction are from the centre of the process plant to the maximum concentration outside the property boundary.

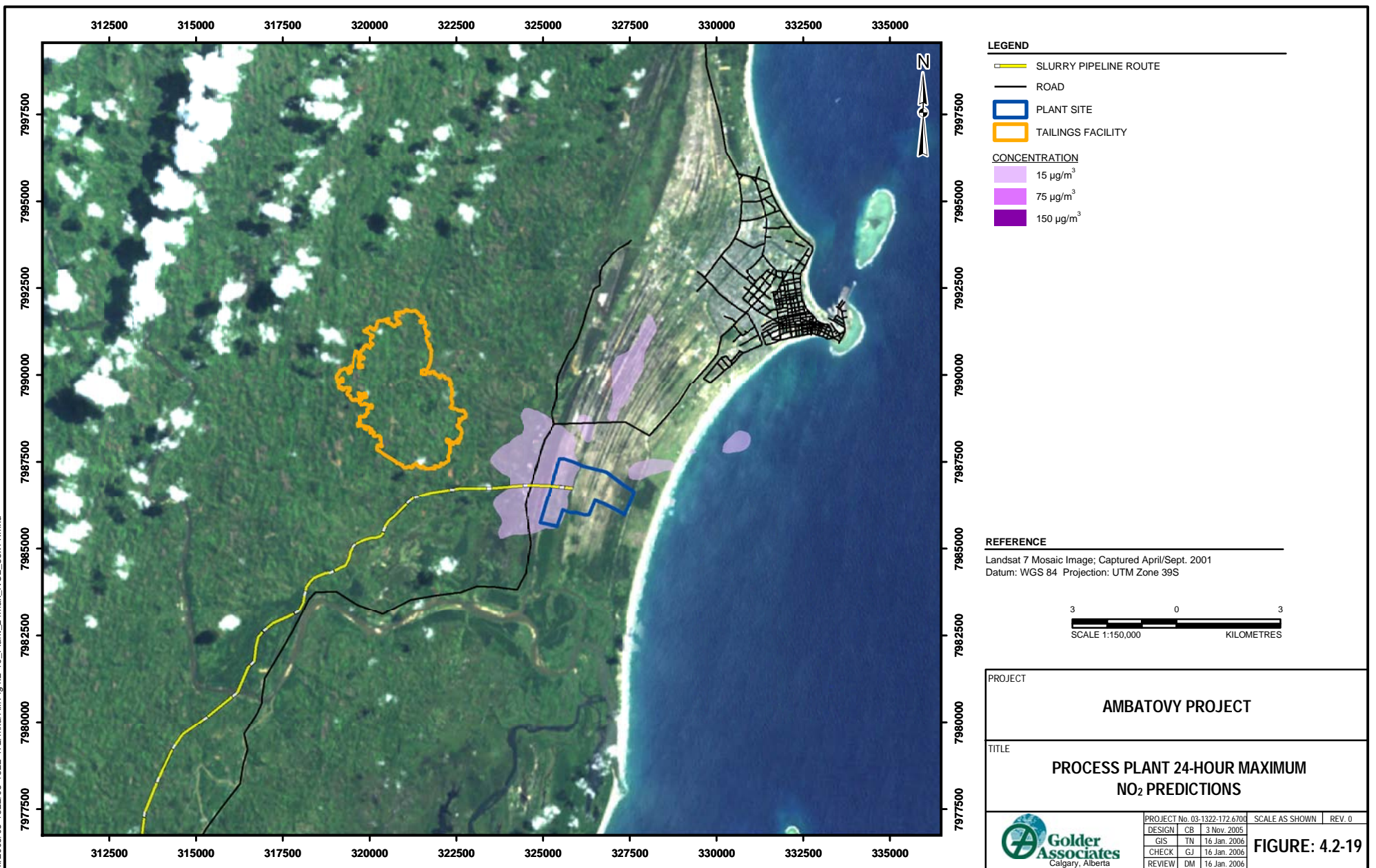
Table 4.2-22 summarizes the maximum predicted 24-hour and annual NO₂ concentrations at each of the regional communities due to emissions from the process plant. These predictions do not include background concentrations of NO₂ from community sources (e.g., vehicle traffic). None of the concentrations exceed the World Bank guidelines for NO₂.

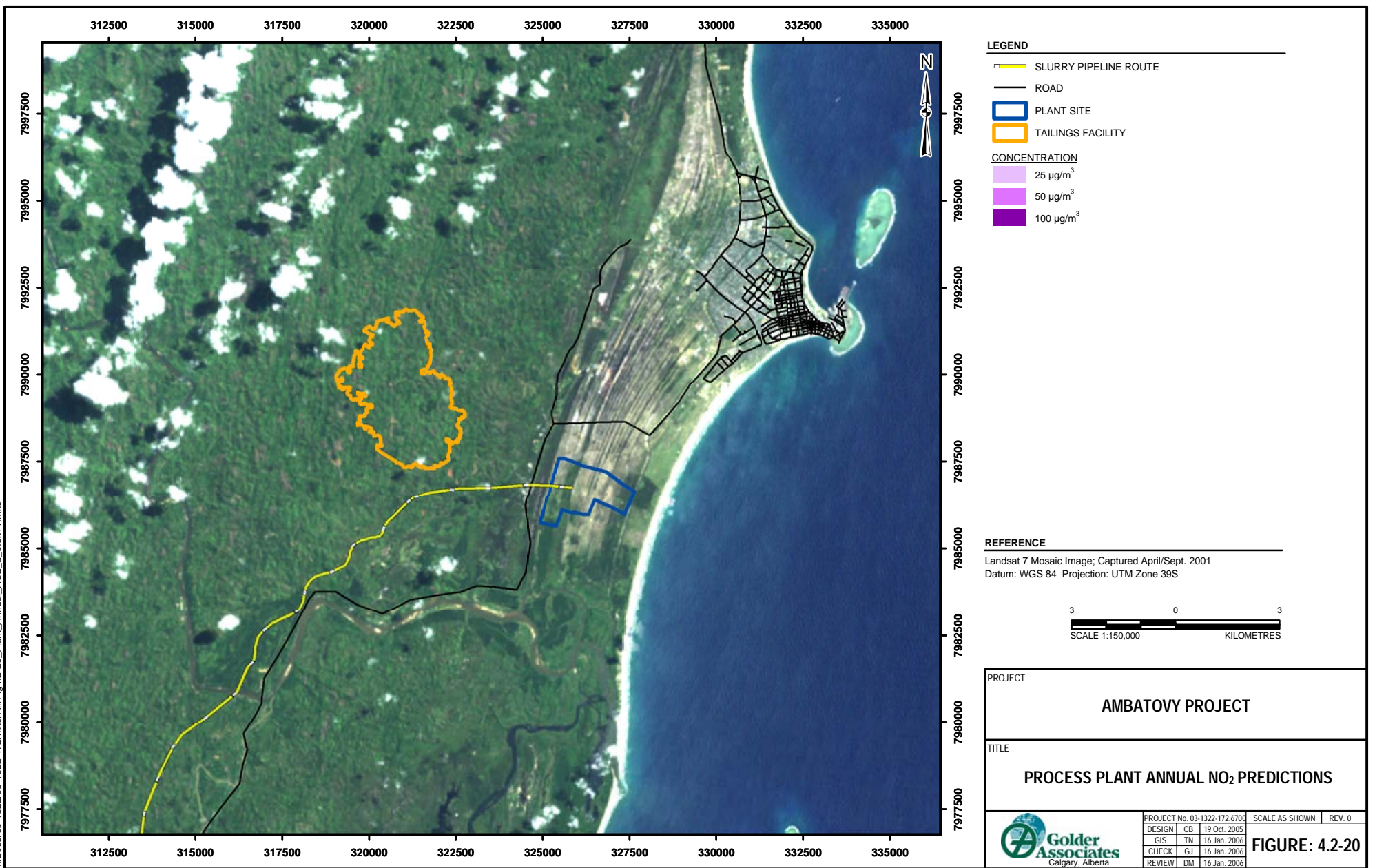
Table 4.2-22 Maximum Predicted NO₂ Concentrations in Communities

Community	Maximum NO ₂ Concentration [µg/m ³]	
	24-Hour	Annual
Ambarimilambana	4.3	0.3
Ambatoroa	16.7	1.8
Amboakarivo	8.3	0.4
Ambodikily	4.1	0.3
Ambodisaina	7.7	0.8
Amboditandroho	5.8	0.3
Ampasimbola	13.6	1.5
Ampasinambo	3.4	0.4
Ampihaonana	3.5	0.5
Ampirasantany	5.4	0.4
Analabe	11.2	1.0
Antananambo	7.4	0.9
Antanandava	10.3	1.1
Antsiranandakana	14.5	1.7
Mahatsara	8.6	0.4
Manamboasio	9.4	1.3
Toamasina	7.7	0.9
Vohitsara	8.5	0.5
World Bank NO₂ Criteria [µg/m³]	150	100

Note: Predicted community concentrations do not include background values.

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4.4.2 Particulate Matter

Tables 4.2-23 presents the 24-hour and annual particulate matter with diameter less than 10 μm (PM_{10}) and the annual Total Suspended Particulate (TSP) predictions resulting from activities at the process plant. The maximum predicted concentrations within the study area are predicted to be below the World Bank criteria. Figures 4.2-21 through 4.2-23 show the maximum 24-hour and annual PM_{10} as well as the annual TSP predictions, respectively.

Table 4.2-23 Particulate Matter Predictions in the Process Plant Study Area

Parameter	Averaging Period	
	24-hour	annual
maximum PM_{10} concentration [$\mu\text{g}/\text{m}^3$]	11.1	1.4
maximum PM_{10} concentration outside property boundary [$\mu\text{g}/\text{m}^3$]	4.5	0.5
distance to maximum concentration [km] ^(a)	0.5	0.5
direction to maximum concentration(a)	NNE	NNE
World Bank PM_{10} Criteria [$\mu\text{g}/\text{m}^3$]	150	50
maximum TSP concentration [$\mu\text{g}/\text{m}^3$]	—	2.4
maximum TSP concentration outside property boundary [$\mu\text{g}/\text{m}^3$]	—	0.8
distance to maximum concentration [km] ^(a)	—	0.5
direction to maximum concentration ^(a)	—	NNE
World Bank TSP Criteria [$\mu\text{g}/\text{m}^3$]	—	50

^(a) Distance and direction are from the centre of the process plant to the maximum concentration outside the property boundary.

“—” indicates no emissions from this source.

Table 4.2-24 summarizes the maximum predicted 24-hour and annual PM_{10} and annual TSP concentrations at each of the regional communities due to emissions from the process plant. These predictions do not include background particulate matter concentrations from community sources (e.g., vehicle traffic). None of the concentrations exceed the World Bank criteria.

4.4.3 Other Compounds

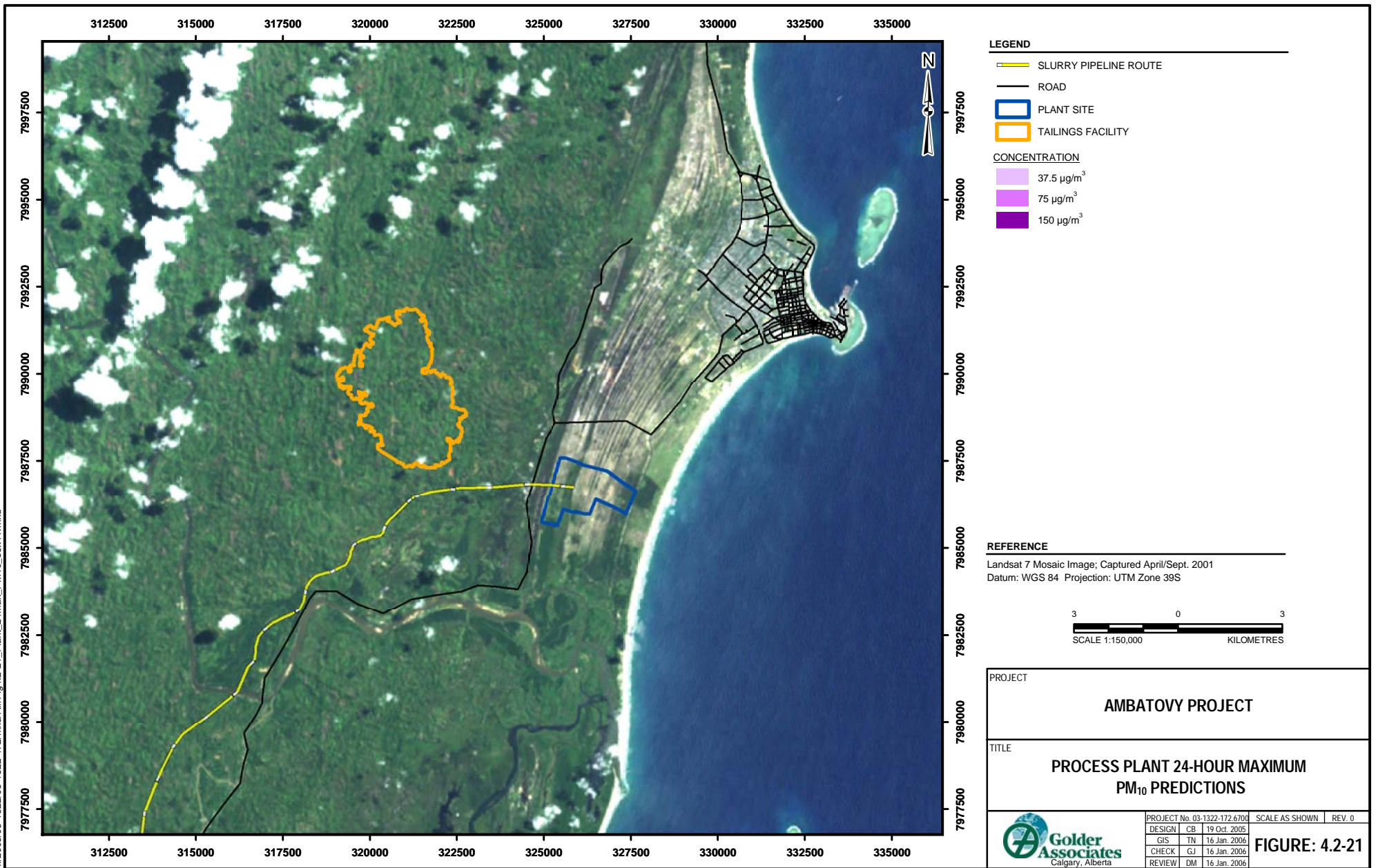
Table 4.2-25 summarizes the maximum predicted 1-hour and 24-hour H_2S concentrations at each of the regional communities due to emissions from the process plant. These predictions do not include background H_2S concentrations from community sources (e.g., vehicle traffic). All the communities except two were predicted to have concentrations over the WHO recommended guideline for odour detection (i.e., 7 $\mu\text{g}/\text{m}^3$); however, the frequencies at all sites were less than 3% of the time (or 263 hours per year).

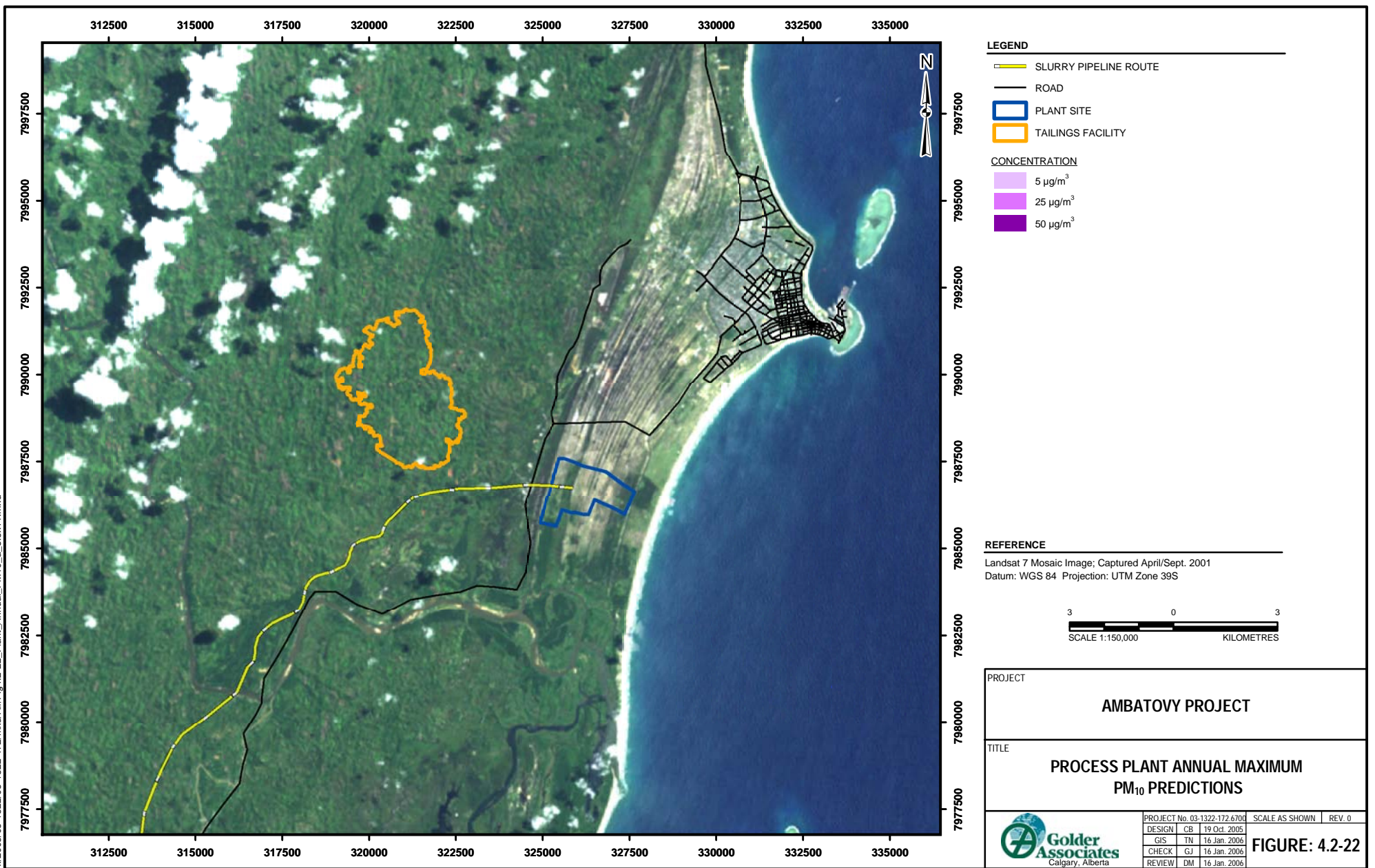
Table 4.2-24 Maximum Predicted Particulate Concentrations in Communities

Community	Maximum TSP Concentration [µg/m³]	Maximum PM ₁₀ Concentration [µg/m³]	
	Annual	24-Hour	Annual
Ambarimilambana	0.0	0.4	0.0
Ambatoroa	0.2	1.5	0.2
Amboakarivo	0.0	0.7	0.0
Ambodikily	0.0	0.3	0.0
Ambodisaina	0.1	0.8	0.1
Amboditandroho	0.0	0.5	0.0
Ampasimbola	0.1	1.1	0.1
Ampasinambo	0.0	0.3	0.0
Ampihaonana	0.0	0.3	0.0
Ampirasantany	0.1	0.5	0.1
Analabe	0.1	1.1	0.1
Antananambo	0.1	0.6	0.1
Antanandava	0.1	0.9	0.1
Antsiranandakana	0.2	1.3	0.2
Mahatsara	0.0	0.7	0.0
Manamboasio	0.2	1.9	0.2
Toamasina	0.1	0.6	0.1
Vohitsara	0.1	0.7	0.1
World Bank Criteria [µg/m³]	80	150	50

Note: Predicted community concentrations do not include background values.

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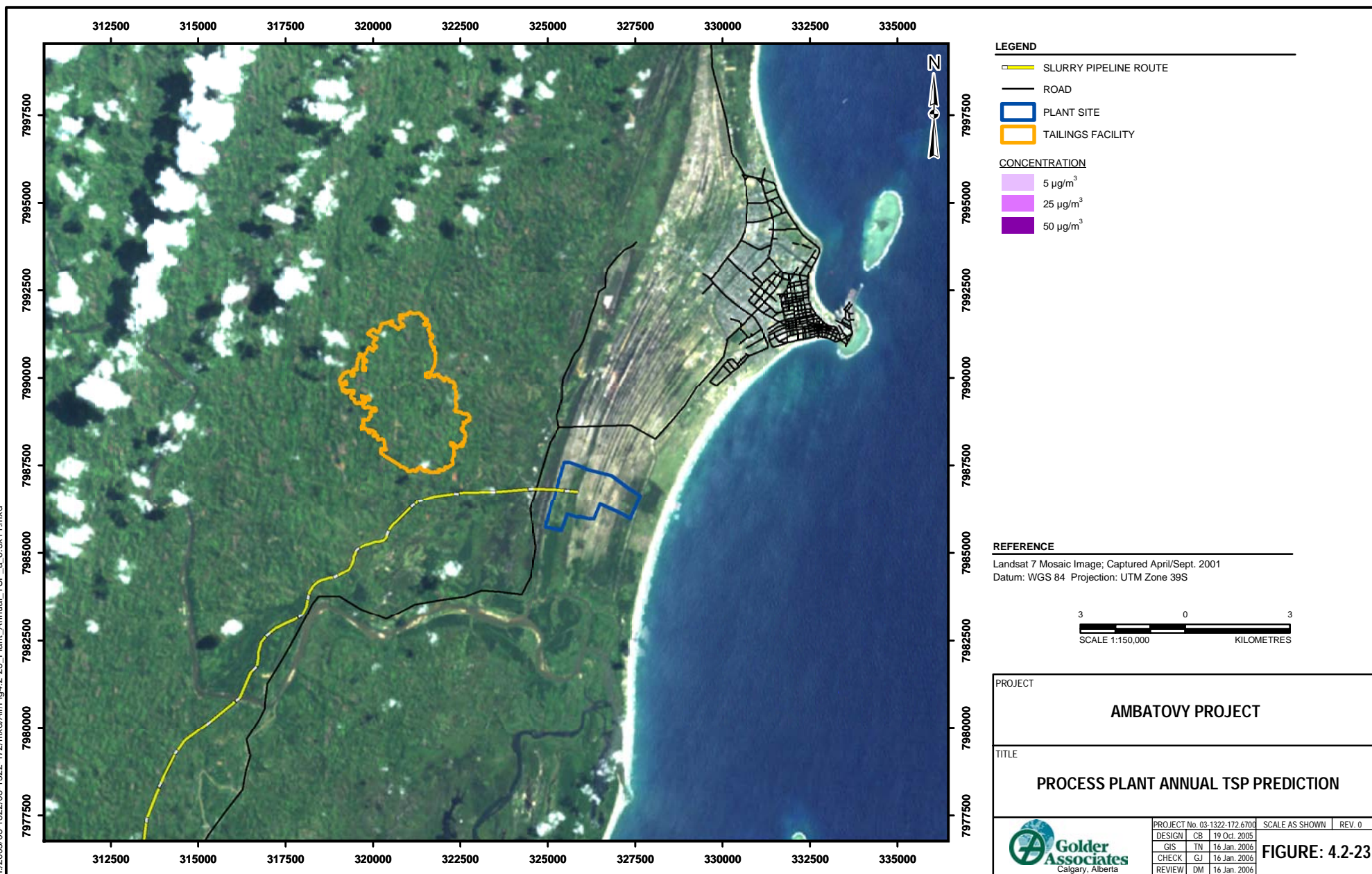


Table 4.2-25 Maximum Predicted H₂S Concentrations in Communities

Community	Maximum 1-Hour Concentration [µg/m ³]	Frequency Above 7 µg/m ³	Maximum 24-Hour Concentration [µg/m ³]
Ambarimilambana	4.3	0.0%	0.6
Ambatoroa	33.7	2.5%	4.9
Amboakarivo	20.6	0.2%	2.2
Ambodikily	5.7	0.0%	0.6
Ambodisaina	16.0	0.1%	1.5
Amboditandroho	7.4	0.0%	1.2
Ampasimbola	24.0	1.4%	5.3
Ampasinambo	4.0	0.0%	0.6
Ampihaonana	7.0	0.0%	0.6
Ampirasantany	35.0	0.1%	1.5
Analabe	29.5	1.1%	3.7
Antananambo	15.8	0.1%	1.2
Antanandava	20.4	0.9%	3.0
Antsiranandakana	27.5	1.4%	3.5
Mahatsara	15.9	0.2%	2.0
Manamboasio	33.5	2.8%	8.8
Toamasina	7.8	0.0%	1.1
Vohitsara	9.4	0.0%	1.5
WHO H₂S Criteria [µg/m³]	7	—	150

Note: Predicted community concentrations do not include background values.

“—” indicates no emissions from this source.

Table 4.2-26 summarizes the maximum predicted annual lead and mercury concentrations at each of the regional communities due to emissions from the process plant. Lead and mercury concentrations were scaled off of particulate concentrations based on the metal content of coal provided in USEPA 1995. These predictions do not include background concentrations from community sources (e.g., vehicle traffic). The concentrations were predicted to be below the WHO guidelines.

4.4.4 Acid Deposition

Potential acid input (PAI) is a method for evaluating the overall effects of acid-forming compounds on the environment since it accounts for the acidifying effect of the sulphur and nitrogen species, as well as the neutralizing effect of available base cations. Figure 4.2-24 shows the contours of acid deposition in the process plant study area.

Table 4.2-26 Maximum Predicted Lead and Mercury Concentrations in Communities

Community	Maximum Annual Concentration [$\mu\text{g}/\text{m}^3$]	
	Lead	Mercury
Ambarimilambana	0.000079	0.000002
Ambatoroa	0.000339	0.000010
Amboakarivo	0.000072	0.000002
Ambodikily	0.000080	0.000002
Ambodisaina	0.000166	0.000005
Amboditandroho	0.000060	0.000002
Ampasimbola	0.000289	0.000009
Ampasinambo	0.000092	0.000003
Ampihaonana	0.000105	0.000003
Ampirasantany	0.000069	0.000002
Analabe	0.000196	0.000006
Antananambo	0.000181	0.000006
Antanandava	0.000217	0.000007
Antsiranandakana	0.000310	0.000009
Mahatsara	0.000082	0.000002
Manamboasio	0.000217	0.000007
Toamasina	0.000159	0.000005
Vohitsara	0.000127	0.000004
WHO Criteria [$\mu\text{g}/\text{m}^3$]	0.5	1

Notes: Predicted community concentrations do not include background values.

4.5 ADDITIONAL MODELLING SCENARIOS

4.5.1 Process Plant With Refinery Case

This section provides an alternative modelling scenario if the refinery were included in the process plant.

4.5.1.1 Emissions

Activities at the process plant will result in the release of emissions of SO_2 , NO_x , particulate matter and H_2S to the atmosphere. The emissions of SO_2 , NO_2 and particulate matter during normal maximum production including the refinery were provided by Dynatec. Sulphur dioxide emissions from the flares and fugitive particulate emissions from the coal and limestone stockpiles were derived by Golder Associates. Flare emissions for normal operations were assumed to be continuous. Sulphur dioxide emissions were calculated based on the gas composition and volumetric flow rate provided by Dynatec.

Table 4.2-27 provides a summary of the process plant emission rates used in the air quality assessment.

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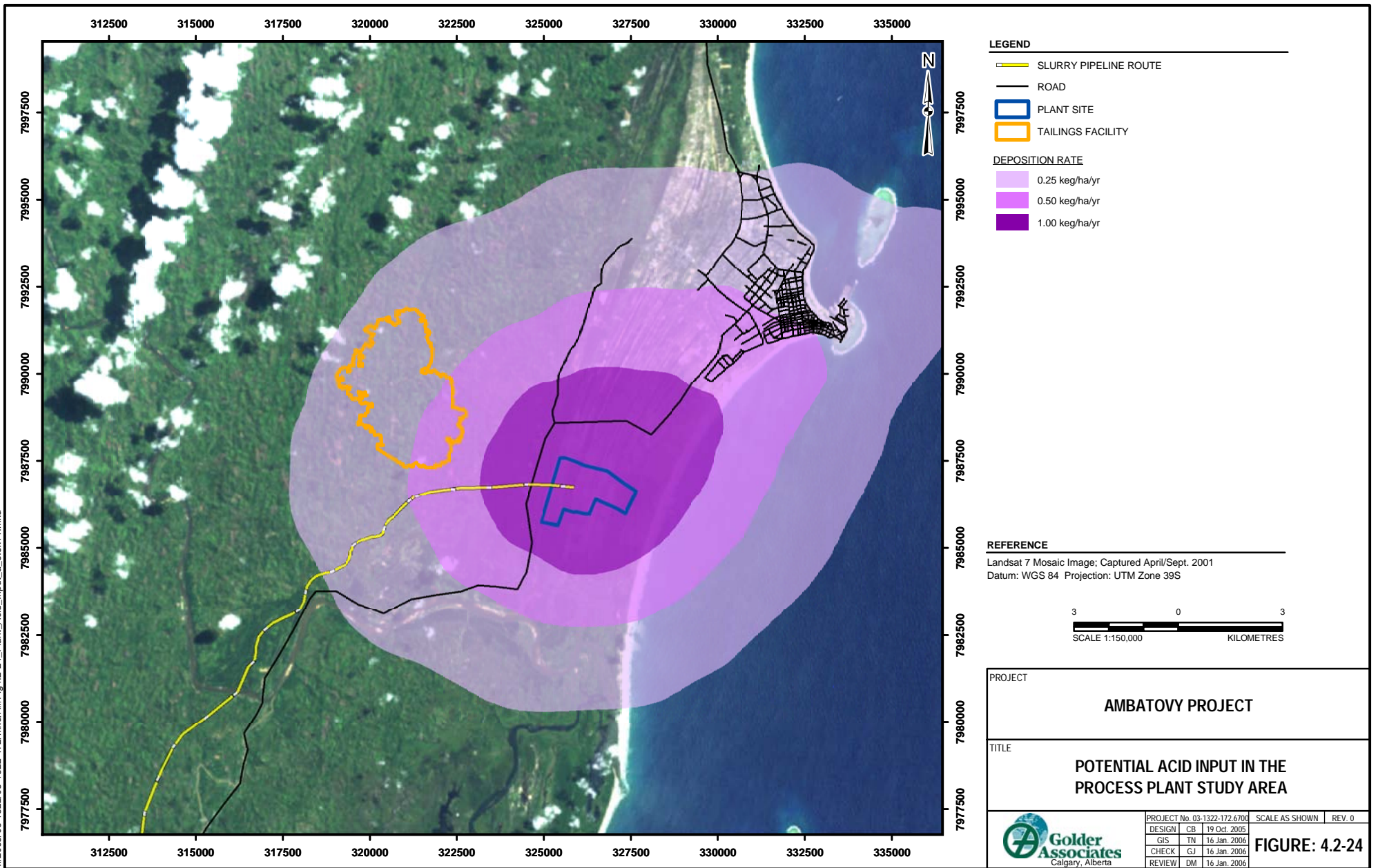


Table 4.2-27 Process Plant Air Emissions Summary – With Refinery

Source	Emission Rate [t/d]			
	SO ₂	NO _x	PM ₁₀	TSP
leach - sulphide area flare	0.04	0.00	—	—
refinery - sintering furnace 1 (nickel)	0.12	0.07	—	—
refinery - sintering furnace 1 heaters	0.01	0.03	—	—
refinery - sintering furnace 2 (nickel)	0.12	0.07	—	—
refinery - sintering furnace 2 heaters	0.01	0.03	—	—
refinery - cobalt sintering furnace	0.04	0.03	—	—
refinery - flare stack	0.01	0.00	—	—
utilities - hydrogen plant (combined)	0.19	0.29	—	—
utilities - hydrogen sulphide flare stack	0.10	0.00	—	—
utilities - sulphur melting, neutralization and filtration	0.01	—	—	—
utilities - acid plant	6.05	—	—	—
utilities - limestone crushing	—	—	0.01	0.01
utilities - limestone calcining	1.34	0.72	0.05	0.05
utilities - lime slaking	—	—	0.00	0.00
utilities – coal-fired boilers	10.70	5.78	0.48	0.48
coal stockpile	—	—	0.01	0.02
limestone stockpile	—	—	0.01	0.02
Total^(a)	18.72	7.02	0.55	0.57

“—” indicates no emissions from this source.

(a) Some numbers are rounded for presentation purposes. Therefore, it may appear that the totals do not equal the sum of the individual values.

4.5.1.2 Air Quality Predictions

The expected emissions of SO₂, NO_x, TSP, and PM₁₀ from the operation of the process plant including the refinery were input into the CALPUFF dispersion model to determine ground-level concentrations within the study area. The CALPUFF model was run in the steady-state (2-D) mode using three years of meteorological observations collected at the Toamasina Airport.

The results of the modelling are presented in the following sections. All modelling results have been presented for the study area outside the process plant boundary.

Sulphur Dioxide

Table 4.2-28 presents the maximum SO₂ predictions resulting from activities at the process plant. Based on the modelling, the maximum 24-hour and annual concentrations are predicted to be below the relevant air quality guidelines.

Table 4.2-28 SO₂ Predictions in the Process Plant Study Area – With Refinery

Parameter	Averaging Period	
	24-hour	Annual
maximum SO ₂ concentration [µg/m ³]	74.9	8.7
maximum SO ₂ concentration outside property boundary [µg/m ³]	74.9	8.7
distance to maximum concentration [km] ^(a)	1.0	1.0
direction to maximum concentration ^(a)	WNW	W
World Bank Criteria for SO₂ [µg/m³]	150	80

^(a) Distance and direction are from the centre of the process plant to the maximum concentration outside the property boundary.

Oxides of Nitrogen

Table 4.2-29 presents the maximum NO₂ predictions resulting from activities at the process plant including the refinery. Based on the modelling, the maximum 24-hour, and annual concentrations are predicted to be below the relevant air quality guidelines.

Table 4.2-29 NO_x and NO₂ Predictions in the Process Plant Study Area – With Refinery

Parameter	Averaging Period	
	24-hour	annual
maximum NO _x concentration [µg/m ³]	25.8	3.1
maximum NO ₂ concentration [µg/m ³]	25.8	3.1
maximum NO ₂ concentration outside property boundary [µg/m ³]	25.8	3.1
distance to maximum concentration [km] ^(a)	1.0	1.0
direction to maximum concentration ^(a)	WNW	W
World Bank Criteria for NO₂ [µg/m³]	150	100

^(a) Distance and direction are from the centre of the process plant to the maximum concentration outside the property boundary.

Particulate Matter

Table 4.2-30 presents the 24-hour and annual particulate matter with diameter less than 10 μm (PM_{10}) and the annual Total Suspended Particulate (TSP) predictions resulting from activities at the process plant. The maximum predicted concentrations within the study area are predicted to be below the World Bank criteria.

Table 4.2-30 Particulate Matter Predictions in the Process Plant Study Area – With Refinery

Parameter	Averaging Period	
	24-hour	annual
maximum PM_{10} concentration [$\mu\text{g}/\text{m}^3$]	11.1	1.4
maximum PM_{10} concentration outside property boundary [$\mu\text{g}/\text{m}^3$]	4.5	0.5
distance to maximum concentration [km] ^(a)	0.5	0.5
direction to maximum concentration ^(a)	NNE	NNE
World Bank Criteria for PM_{10} [$\mu\text{g}/\text{m}^3$]	150	50
maximum TSP concentration [$\mu\text{g}/\text{m}^3$]	—	2.4
maximum TSP concentration outside property boundary [$\mu\text{g}/\text{m}^3$]	—	0.8
distance to maximum concentration [km] ^(a)	—	0.5
direction to maximum concentration ^(a)	—	NNE
World Bank Criteria for TSP [$\mu\text{g}/\text{m}^3$]	—	50

^(a) Distance and direction are from the centre of the process plant to the maximum concentration outside the property boundary.

“—” indicates no emissions from this source.

4.5.2 Upset Process Plant Events

Two upset scenarios were evaluated for the process plant (no refinery). The first scenario involves flaring during regular maintenance of the process plant. In this case, the H_2S flare was assumed to be operating in conjunction with other process plant sources. The second scenario is during emergency shutdown of the plant when both flares would be in use.

For the purposes of modelling emissions from H_2S flare stacks, a series of pseudo-stack characteristics must be determined. The pseudo-stack parameters allow for the simulation of the unconfined combustion of a flare to be simulated with the CALPUFF dispersion model. The calculation of the required parameters assumes the following:

- the pseudo-height of the flare is equal to the height of the flame tip;

- the plume rise is determined on the basis of the buoyancy flux provided by the heat of combustion;
- the pseudo-diameter of the flare is determined by simultaneously solving the buoyancy flux equation for a stack and a flare;
- the velocity of the flared gas is calculated from the flare diameter and the volume of gas discharged; and
- the flare is assumed to have a pseudo-temperature of 1,000°C.

The following formulation is used to derive the pseudo-height. This is based on the assumption that the flame will be tilted at an angle of 45° from the vertical (USEPA 1992a).

$$h_{pseudo} = h_{stack} + \underbrace{4.56 \times 10^{-3} \times H^{0.478}}_{\text{flame height}}$$

where:

$$\begin{aligned} h_{pseudo} &= \text{the pseudo-height of the stack [metres]} \\ h_{stack} &= \text{the physical flare stack height [metres]} \\ H &= \text{the total heat release of the flare [cal/s]} \end{aligned}$$

The buoyancy flux formulation for the flare have been based on the Briggs (1969) formulation, assuming that 55% of the heat released from the flare is radiated into the atmosphere (Leahey and Davies 1984). Recent guidance from Alberta Environment (AENV 2000) recommends that the flaring calculations should be made assuming that only 25% of the heat released is radiated to the atmosphere. The formulation is as follows:

$$F_{b(flare)} = \frac{g \times Q_H}{\pi \times \rho \times c_p \times T_a}$$

and

$$Q_H = (1 - H_{rad}) \times H$$

where:

$$\begin{aligned} F_{b(flare)} &= \text{the buoyancy flux from the flare [m}^4\text{/s}^3\text{]} \\ g &= \text{gravitational acceleration [m/s}^2\text{]} \\ Q_H &= \text{the sensible heat release rate [cal/s]} \\ H &= \text{the total heat release of the flare [cal/s]} \\ H_{rad} &= \text{the fraction of heat lost to radiation [25\%]} \end{aligned}$$

ρ	=	the gas density [1,205 g/m ³]
c_p	=	the specific heat of the gas [0.24 cal/K]
T_a	=	the ambient temperature [293 K]

Using the above, it is then possible to determine the pseudo stack parameters required for achieving the same buoyancy flux from a non-flare source. Simultaneously solving the buoyancy flux formula for a point source (Briggs 1975) and the flare buoyancy flux noted above will accomplish this:

$$F_{b(stack)} = F_{b(flare)}$$

or

$$g \times v_s \times d_{pseudo}^2 \times \left(\frac{T_s - T_a}{4 \times T_s} \right) = \frac{g \times (1 - H_{rad}) \times H}{\pi \times \rho \times c_p \times T_a}$$

where:

$F_{b(stack)}$	=	the buoyancy flux of the pseudo stack (m ⁴ /s ³)
g	=	gravitational acceleration [m/s ²]
v_s	=	the release velocity [m/s]
d_{pseudo}	=	the pseudo-diameter of the stack [m]
T_s	=	the release temperature [1,273 K]
T_a	=	the ambient temperature [293 K]
H	=	the total heat release of the flare [cal/s]
ρ	=	the gas density [1,205 g/m ³]
c_p	=	the specific heat of the gas [0.24 cal/K]
T_a	=	the ambient temperature [293 K]

By rearranging the above formula, it can be simplified in the following manner:

$$d_{pseudo}^2 = \frac{g \times (1 - H_{rad}) \times H \times 4 \times T_s}{\pi \times \rho \times c_p \times T_a \times g \times v_s \times (T_s - T_a)}$$

or

$$d_{pseudo} = 3.829 \times 10^{-3} \sqrt{\frac{H}{v_s}}$$

where:

d_{pseudo}	=	the pseudo-diameter of the stack [m]
--------------	---	--------------------------------------

$$H = \text{the total heat release of the flare [cal/s]}$$

$$v_s = \text{the release velocity [m/s]}$$

4.5.2.1 Upset Scenario 1: Maintenance Flaring

There are several maintenance flaring scenarios; however, the scenario with the highest emissions is during the startup or shutdown of the hydrogen plant when the hydrogen sulphide flare is used. This event is expected to occur 12 times per year with a duration of 0.5 hours per event.

Emissions

The remainder of the process plant was assumed to be operating at the same time as the maintenance event. The SO₂ and H₂S emissions from the plant (excluding the hydrogen sulphide flare) are 15.69 t/d and 0.24 t/d, respectively. Table 4.2-31 presents the hydrogen sulphide flare characteristics and emissions used in the model.

Table 4.2-31 Flare Parameters and Emissions for Maintenance Flaring Scenario

Component	Value
typical flared gas volume [m ³ /d]	36,944
fraction of C ₁ to C ₄ [molar %]	0.00%
fraction of C ₅ [molar %]	0.00%
fraction of H ₂ S [molar %]	39.80%
lower heating value [MJ/m ³]	8.72
total heat release [MJ/s]	3.73
pseudo-height [m]	43.18
pseudo-diameter [m]	1.47
exit velocity [m/s]	6.05
pseudo-temperature ^(a) [°C]	1,000
SO ₂ emission rate [t/d]	19.49
H ₂ S emission rate ^(b) [t/d]	0.21

^(a) Assumed for the purposes of dispersion modelling.

^(b) Assumed that 98% of the inlet sulphur to the flare (in the form of hydrogen sulphide, H₂S) was converted to SO₂.

Modelling Results

Table 4.2-32 summarizes the maximum SO₂ concentrations associated with the maintenance flaring scenario. The maximum 1-hour concentration outside the plant property boundary was predicted to be 1,215 µg/m³. Since there are no international guidelines for 1-hour SO₂, the 10-minute WHO criteria of

500 µg/m³ was used as a comparison. It is important to recognize that the probability of high SO₂ concentrations are with respect to adverse meteorological conditions. That is, the frequencies shown in Table 4.2-32 assume continuous flaring and do not take into account the low probability of flaring actually occurring. When flaring duration is taken into account (i.e., 6 hours per year or 0.07% probability), the maximum probability of an occurrence above the guideline value outside the property boundary is only 0.001%.

Table 4.2-32 Maximum SO₂ Predictions for Maintenance Flaring Scenario

Location	1-Hour Maximum [µg/m ³]	Frequency of Occurrence Above 500 µg/m ^{3(a)}
Including plant property boundary	1,322.6	2.4%
Outside plant property boundary	1,215.4	1.8%

^(a) The WHO criteria for 10 minute SO₂ is 500 µg/m³. The frequency is determined assuming continuous flaring.

Table 4.2-33 summarizes the maximum H₂S concentrations associated with the maintenance flaring scenario. The maximum 1-hour concentration outside the plant property boundary was predicted to be 50 µg/m³. Since there are no international guidelines for 1-hour H₂S, the 30-minute WHO recommended criteria for odour detection of 7 µg/m³ was used as a comparison. As discussed above, the frequencies shown in Table 4.2-33 assume continuous flaring and do not take into account the low probability of flaring actually occurring. When flaring duration is taken into account, the maximum probability of an occurrence above the criteria outside the property boundary is only 0.004%.

Table 4.2-33 Maximum H₂S Predictions for Maintenance Flaring Scenario

Location	1-Hour Maximum [µg/m ³]	Frequency of Occurrence Above 7 µg/m ^{3(a)}
Including plant property boundary	62.3	7.8%
Outside plant property boundary	50.2	5.9%

^(a) The WHO criteria for 30 minute H₂S is 7 µg/m³. The frequency is determined assuming continuous flaring.

4.5.2.2 Upset Scenario 2: Emergency Flaring

There are several emergency flaring scenarios; however, the scenario with the highest expected emissions is during complete shutdown of the process plant when both the sulphide area flare and the hydrogen sulphide flare would be

flaring. This event could occur four times per year with a duration of five minutes per event.

Emissions

Table 4.2-34 presents the SO₂ and H₂S emissions and flare characteristics of the sulphide area and hydrogen sulphide flares.

Table 4.2-34 Flare Parameters and Emissions for Emergency Flaring Scenario

Component	Sulphide Area Flare	Hydrogen Sulphide Flare
typical flared gas volume [m ³ /d]	193,606	261,527
fraction of C ₁ to C ₄ [molar %]	0.00%	0.00%
fraction of C ₅ [molar %]	0.00%	0.00%
fraction of H ₂ S [molar %]	65.60%	97.00%
lower heating value [MJ/m ³]	14.37	21.25
total heat release [MJ/s]	32.21	64.33
pseudo-height [m]	48.92	52.42
pseudo-diameter [m]	1.57	2.29
exit velocity [m/s]	45.65	42.82
pseudo-temperature ^(a) [°C]	1,000	1,000
SO ₂ emission rate [t/d]	27.94	55.81
H ₂ S emission rate ^(b) [t/d]	0.30	0.61

^(a) Assumed for the purposes of dispersion modelling.

^(b) Assumed that 98% of the inlet sulphur to the flare (in the form of hydrogen sulphide, H₂S) was converted to SO₂.

Modelling Results

Table 4.2-35 summarizes the maximum SO₂ concentrations associated with the emergency flaring scenario. The maximum 1-hour concentration outside the plant property boundary was predicted to be 885 µg/m³. Since there are no international guidelines for 1-hour SO₂, the 10-minute WHO criteria of 500 µg/m³ was used as a comparison. It is important to recognize that the probability of high SO₂ concentrations are with respect to adverse meteorological conditions. That is, the frequencies shown in Table 4.2-35 assume continuous flaring and do not take into account the low probability of flaring actually occurring. When flaring duration is taken into account (i.e., 20 minutes per year or 0.004% probability), the maximum probability of an occurrence above the guideline value outside the property boundary is only 0.000003%.

Table 4.2-35 Maximum SO₂ Predictions for Emergency Flaring Scenario

Location	1-Hour Maximum [µg/m ³]	Frequency of Occurrence Above 500 µg/m ^{3(a)}
Including plant property boundary	884.7	0.4%
Outside plant property boundary	884.7	0.1%

^(a) The WHO criteria for 10 minute SO₂ is 500 µg/m³. The frequency is determined assuming continuous flaring.

Table 4.2-36 summarizes the maximum H₂S concentrations associated with the emergency flaring scenario. The maximum 1-hour concentration outside the plant property boundary was predicted to be 10 µg/m³. Since there are no international guidelines for 1-hour H₂S, the 30-minute WHO recommended criteria for odour detection of 7 µg/m³ was used as a comparison. As discussed above, the frequencies shown in Table 4.2-36 assume continuous flaring and do not take into account the low probability of flaring actually occurring. When flaring duration is taken into account, the maximum probability of an occurrence above the criteria outside the property boundary is only 0.000001%.

Table 4.2-36 Maximum H₂S Predictions for Emergency Flaring Scenario

Location	1-Hour Maximum [µg/m ³]	Frequency of Occurrence Above 7 µg/m ³
including plant property boundary	9.6	0.05%
outside plant property boundary	9.6	0.02%

^(a) The WHO criteria for 30 minute H₂S is 7 µg/m³. The frequency is determined assuming continuous flaring.

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VOLUME I: PHYSICAL APPENDICES

APPENDIX 5.1

NOISE SURVEY BASELINE

Submitted to:

Dynatec Corporation

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1 INTRODUCTION

This baseline noise study was conducted for the Ambatovy Project (the project) to establish existing noise levels at the project sites, to study the Environmental Assessment of noise, and to meet the requirements of the World Bank.

2 NOISE TERMINOLOGY

Since some of the concepts and theories used in the assessment of outdoor acoustics are not intuitive, the following descriptions of key concepts and definitions used in this evaluation are provided to guide the reader.

- *Sound* or *sound emissions* refers to the acoustic energy generated by natural or man-made sources, including the project activities.
- *Noise* or *noise levels* refers to the levels that can be heard or measured at a receiver.
- A noise *receiver* is a location where measurements or predictions of noise levels are made.
- The *volume* of a sound or noise is expressed on a logarithmic scale, in decibels (dB). Since the scale is logarithmic, a sound or noise that is twice as loud as another will only be three decibels (3 dB) higher. A sound or noise with double the number of decibels is much more than twice as loud. A change of three decibels is also the general threshold at which a person can notice a change in sound volume.
- Sound emissions and noise levels also have a *frequency*. The human ear does not respond to all frequencies in the same way. Mid-range frequencies are most readily detected by the human ear, while low and high frequencies are harder to hear. Environmental noise levels are usually presented as *A weighted* decibels (or dBA), which incorporates the frequency response of the human ear. While low frequency noise may not be *heard*, it can often be felt.

Outdoor noise is usually expressed as an *equivalent noise level* (L_{eq}), which is a logarithmic average of the measured or predicted noise levels over a given period of time. This type of average takes into account the natural variability of sound.

Table 5.1-1 lists noise levels from common sources that provide a reference when comparing the background noise levels measured for the project. The noise levels listed in the table represent average values and could vary from one situation to the next.

Table 5.1-1 Summary of Noise Levels Associated With Common Activities

Activity	Noise Level [dBA]
lawnmower	95
loud shout	90
motorcycle passing 15 m away	85
car travelling 100 km/hr passing 15 m away	80
vacuum cleaner	75
faucet	62
normal conversation	60
moderate rainfall	50
bird singing	50
quiet living room	40
whispered speech	40
average rural sound level at night	35

3 METHODS

Since Madagascar does not have established guidelines or regulations concerning noise measurements, the study was performed to meet the requirements of the World Bank. The World Bank requires noise be assessed at receptors that lie outside the project boundary based on day and night criteria. World Bank lists daytime hours from 7:00 AM to 10:00 PM and nighttime hours from 10:00 PM to 7:00 AM (WB, 1998). In order to establish baseline at receptors, measurements were made at representative locations during day and night hours. Specific criteria within these time periods are discussed in detail in the Noise Environmental Assessment Reports in volumes B, C, D, E and F.

Weather data was measured at receptor locations during each 24-hour monitoring period. Noise measurements are most accurate during weather conditions conducive to low relative humidity, warm temperatures (below 30°C), low winds and no cloud cover. Weather information was recorded throughout the monitoring period to ensure conditions remained optimal for noise measuring.

During periods of rain and high winds, monitoring was stopped due to invalid data. Rain and high wind interferes with the background noise conditions and will create higher baselines than what is actually representative of the area. During data analysis, times when winds are high or periods of rain are removed from the data set and day and night values recalculated.

The study, consisting of four, 24-hour continuous noise surveys and spot measurements with weather information recorded. The program was conducted from August 12 to 30, 2004.

3.1 MONITORING METHODS

One, 24-hour survey was conducted at each monitoring station to represent existing noise levels at sensitive receptors around the major project noise contributors. Surveys of this type and duration provide information on daily variability in noise levels.

A model 2238 Brüel and Kjaer Type I integrating sound level meter was used to collect the measurements. A Type 4231 Calibrator was used for calibrating the meter before and after each monitoring sequence. The calibrator has an estimated uncertainty for sound pressure level of ± 0.12 dB at a 99% confidence level. Calibration was performed before and after each 24-hour monitoring period.

The meter recorded average (L_{eq}) and maximum (L_{max}) sound pressure levels once per minute during the monitoring period. The data were then downloaded to a computer for further analysis with the Brüel and Kjaer 7821 Evaluator® software program.

Temperature, wind speed and wind direction were recorded throughout each monitoring period. A temperature gauge and Kestrel 1000 pocket wind meter recorded temperature and wind measurements at the monitoring sites. Other observations recorded during the surveys included precipitation, cloud cover and audible noise sources.

One-minute L_{eq} data were summarized over each hour, day (7:00 AM to 10:00 PM) and night (10:00 PM to 7:00 AM). Standard logarithmic formulae for the calculation of L_{eq} values of data were required to determine an hourly L_{eq} value.

3.2 MONITORING LOCATIONS

A series of potential monitoring locations, based on the expected proximity of houses to the project, was selected before visiting the site. Final site selections were established in the field once on-site evaluations were conducted. Sites were selected based on the extent of project activities, the expected sound level emissions and locations of sensitive receptors. Where project sites were adjacent to each other, (e.g., Plant and Tailings sites) study areas were combined to provide overall results. Figures 5.1-1 and 5.1-2 show the locations of the monitoring sites. The following sections describe each monitoring location and their respective primary existing noise sources.

3.2.1 Mine Site

3.2.1.1 Behontsa Site

The Behontsa monitoring station was established at coordinates (NAD 83) 216289 E, 7913307 S. Behontsa is a village of five houses located on a mountain slope on the border of the Ambatovy transitional forest. The site is covered by bush and rice fields. Existing sources of noise are pets, people and wildlife.

3.2.1.2 Berano Site

The Berano monitoring station was established at coordinates (NAD 83) 218633 E, 7914114 S. Berano is a village of about 15 homes in a valley

surrounded by forest. A road passes through the centre of town. This site is located 6 km by road to the northeast of the mine camp and southeast of the proposed Analamay mine area. Existing sources of noise are daily activities by the villagers, people, pets and wildlife.

3.2.2 Slurry Pipeline

The only sources of noise for the pipeline will be construction activity. The assessment will be a qualitative discussion. Existing noise levels will be based on measurements taken at similar towns and villages to those along the pipeline.

The only source of operations noise associated with the pipeline is the pumping station located on the Mine Site.

3.2.3 Process Plant Site

3.2.3.1 Amboakarivo Site

The Amboakarivo monitoring station was established at coordinates (NAD 83) 326350 E, 7983957 S. Amboakarivo is a small village located 2 km south of the potential plant site boundary. The location is in a clearing approximately 300 m² surrounded by a large garden and forest with a school and houses in the cleared area. The existing noise sources at this location are people, birds and a crew working on the school building.

3.2.4 Tailings Facility

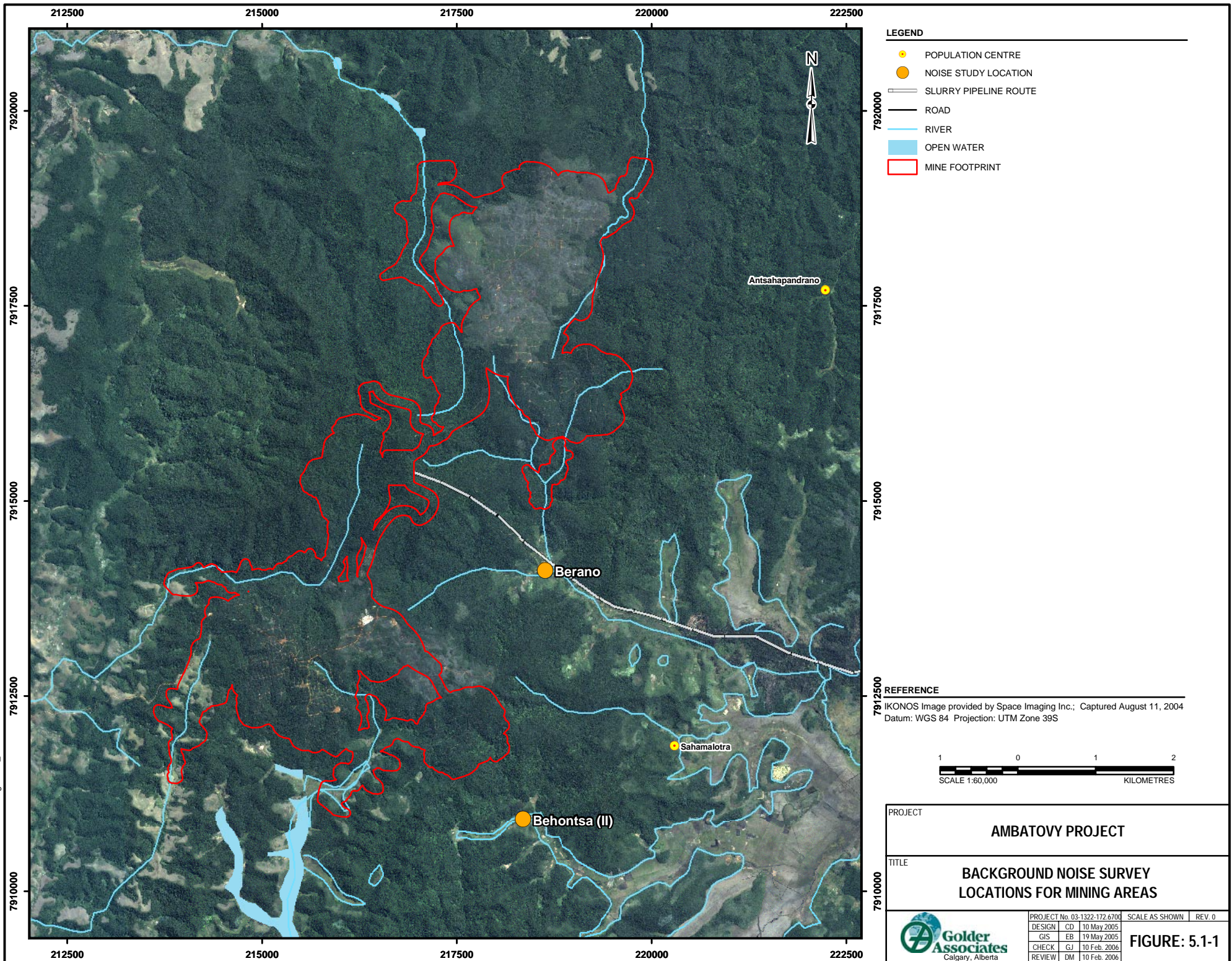
3.2.4.1 Fiadanana Site

The Fiadanana monitoring station was established at coordinates (NAD 83) 324950 E, 7988099 S. Fiadanana is a village of about 20 homes located along the Route National 2 (RN2) road. The area is a rejuvenated cinnamon plantation and is surrounded by bog trees. A manufacturing plant is being built in the village. Therefore, construction at the manufacturing site was the major existing noise source, specifically an excavator working in the area.

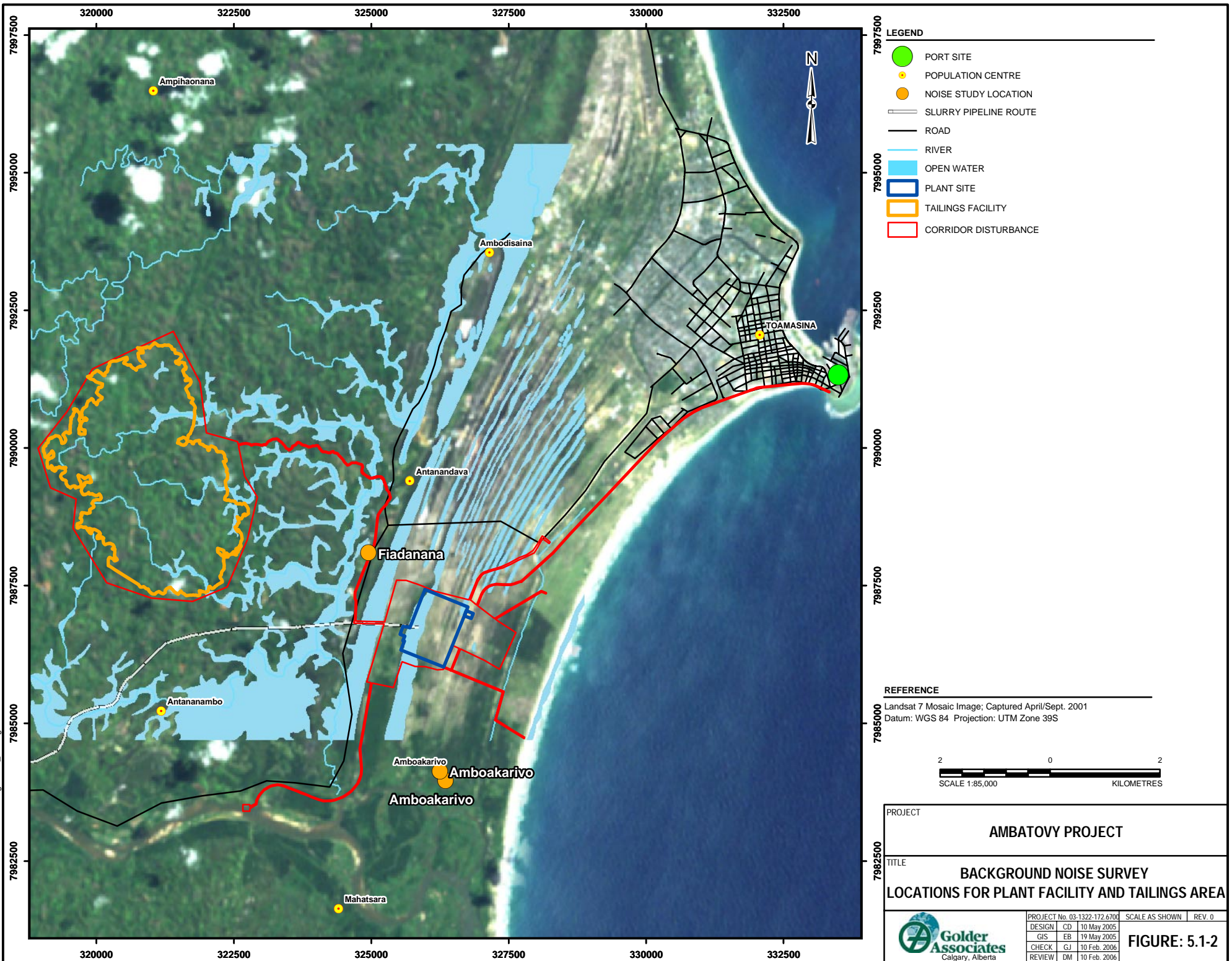
3.2.5 Port Site

The assessment of noise due to shipping traffic will be a qualitative discussion. Expected existing noise levels will be estimated based on the relative location of residences to the docking area.

I:\2003\03-1322\03-1322-172\mxd\Noise\Fig.5.1-1_MineSite6.5x11.mxd



I:/2003/03-1322/03-1322-172/mxd/Noise/Fig.5.1-2 TailingsSite8 5x11.mxd



4 RESULTS

Weather information for the four, 24-hour surveys conducted from August 12 to August 30, 2004 were taken during the monitoring periods. Each location presented its issues with weather; rain being the biggest obstacle. Observed weather information was recorded at each station and is summarized in Table 5.1-2. This summary is presented to confirm that typical local weather conditions were encountered at the time of the surveys. Weather conditions can have a large effect on the results of noise surveys.

Table 5.1-2 Observed Average Weather Conditions at the Monitoring Locations

Date	Temperature [°C]	Wind Speed [m/h]	Wind Direction
Amboakarivo	18 to 36	0 to 1.2	NW
Fiadanana	15 to 39	0 to 1.6	NW
Behontsa	11 to 20	0	N/A
Berano	4 to 28	0	N/A

N/A = No data collected.

Each site has its own unique features and noise characteristics. Sections 4.2 to 4.6 indicate the noise characteristics found in each location. Where the full monitoring cycle was not completed, partial results were used.

4.1 MINE SITE

4.1.1 Behontsa Site

Observed weather information for the 24-hour survey conducted from August 19 to August 20, 2004 is provided in Table 5.1-3. Periods of rain disturbed the study; however, 22 hours and 21 minutes of data were retained and analyzed.

Table 5.1-3 Observed Weather Conditions at Behontsa Site

Date	Hour	Temperature [°C]	Wind Speed [m/h]
August 19, 2004	5:28 PM	14	0
August 19, 2004	10:10 PM	12	0
August 20, 2004	1:30 AM	11	0
August 20, 2004	1:44 AM	12	0
August 20, 2004	8:31 AM	14	0
August 20, 2004	9:24 AM	17	0
August 20, 2004	2:05 PM	20	0
August 20, 2004	3:24 PM	19	0
August 20, 2004	6:31 PM	14	0

Note: Wind direction data not available for this site.

Hourly L_{eq} results of the 24-hour noise survey at Behontsa Site are shown in Table 5.1-4. The quietest hourly L_{eq} during the monitoring period was 33.4 dBA which occurred between 2:31 AM and 3:31 AM on August 20, 2004.

Table 5.1-4 Hourly Sound Levels Recorded at Behontsa Site on August 19 and 20, 2004

Date	Hour	Daytime or Nighttime Period	Sound Levels [dBA]	
			L_{eq}	L_{max}
August 19, 2004	5:31 PM ^(a)	daytime	37.1	59.7
August 19, 2004	6:31 PM ^(a)	daytime	37.5	51.1
August 19, 2004	9:31 PM ^(a)	nighttime	34.1	41.0
August 20, 2004	1:47 AM ^(a)	nighttime	34.6	53.2
August 20, 2004	2:31 AM	nighttime	33.4	42.8
August 20, 2004	3:31 AM ^(a)	nighttime	34.7	41.6
rain delay	—	—	—	—
August 20, 2004	8:32 AM	daytime	44.8	79.0
August 20, 2004	9:32 AM	daytime	39.2	66.8
August 20, 2004	10:32 AM	daytime	47.8	75.0
August 20, 2004	11:32 AM	daytime	39.4	65.5
August 20, 2004	12:32 PM	daytime	37.8	58.7
August 20, 2004	1:32 PM	daytime	44.3	73.9
August 20, 2004	2:32 PM	daytime	41.8	72.5
15-Hour Daytime	—	—	42.2	—
9-Hour Nighttime	—	—	34.1	—
24-Hour Overall	—	—	41.5	—

^(a) Measurement contains invalid data; therefore this hour is based on less than 60 minutes of data.

The average hourly L_{eq} values during the daytime and nighttime periods were 42.2 and 34.1 dBA, respectively. The noise sources that were recorded or observed were from pets, people and wildlife.

The one-minute noise levels ranged between 30.9 and 82.7 dBA. Data is shown graphically in Volume I-5.1, Attachment 1 Figure 1. The graph also shows where invalid data were excluded.

4.1.2 Berano Site

Observed weather information for the 24-hour survey conducted from August 20 to August 21, 2004 is provided in Table 5.1-5. Weather conditions during the program were ideal for noise monitoring. Twenty-four hours of data were retained and analyzed.

Table 5.1-5 Observed Weather Conditions at Berano Site

Date	Hour	Temperature [°C]	Wind Speed [m/h]
August 20, 2004	6:31 PM	14	0
August 21, 2004	12:24 AM	4	0
August 21, 2004	9:28 AM	25	0
August 21, 2004	2:55 PM	28	0
August 21, 2004	5:08 PM	11	0
August 21, 2004	6:25 PM	11	0

Note: Wind direction data not available for this site.

Hourly L_{eq} results of the 24-hour noise survey at Berano Site are shown in Table 5.1-6. The quietest hourly L_{eq} during the monitoring period was 19.9 dBA which occurred between 2:31 AM and 4:31AM on August 21, 2004.

The average hourly L_{eq} values during the daytime and nighttime periods were 41.3 and 40.2 dBA, respectively. The noise sources that were recorded or observed come from daily activities by the villagers, people, pets and wildlife.

The one-minute L_{eq} noise levels ranged between 19.9 and 64.5 dBA. Data are shown graphically in Volume I-5.1, Attachment 1 Figure 2. The graph also shows where invalid data were excluded.

Table 5.1-6 Hourly Sound Levels Recorded at Berano Site on August 20 and 21, 2004

Date	Hour	Daytime or Nighttime Period	Sound Levels [dBA]	
			L _{eq}	L _{max}
August 20, 2004	6:31 PM	daytime	34.8	60.2
August 20, 2004	7:31 PM	daytime	26.9	53.7
August 20, 2004	8:31 PM	daytime	23.2	38.0
August 20, 2004	9:31 PM	daytime	23.5	43.0
August 20, 2004	10:31 PM	nighttime	21.0	51.8
August 20, 2004	11:31 PM ^(a)	nighttime	21.1	45.1
battery change	—	—	—	—
August 21, 2004	12:41 AM ^(a)	nighttime	25.2	63.8
August 21, 2004	1:31 AM	nighttime	25.7	55.5
August 21, 2004	2:31 AM	nighttime	19.9	41.7
August 21, 2004	3:31 AM	nighttime	19.9	32.6
August 21, 2004	4:31 AM	nighttime	35.2	56.1
August 21, 2004	5:31 AM	nighttime	40.0	68.3
August 21, 2004	6:31 AM	nighttime	49.0	86.7
August 21, 2004	7:31 AM	daytime	45.6	75.8
August 21, 2004	8:31 AM ^(a)	daytime	44.9	76.6
Battery change	—	—	—	—
August 21, 2004	9:47 AM ^(a)	daytime	35.6	64.5
Battery change	—	—	—	—
August 21, 2004	10:31 AM	daytime	42.1	71.0
August 21, 2004	11:31 AM	daytime	30.3	56.7
August 21, 2004	12:31 PM	daytime	37.6	69.9
August 21, 2004	1:31 PM	daytime	36.7	55.7
August 21, 2004	2:31 PM	daytime	41.3	69.7
August 21, 2004	3:31 PM	daytime	38.1	65.3
August 21, 2004	4:31 PM	daytime	48.3	75.3
August 21, 2004	5:31 PM	daytime	41.4	65.0
15-Hour Daytime	—	—	41.3	—
9-Hour Nighttime	—	—	40.2	—
24-Hour Overall	—	—	41.0	—

^(a) Measurement contains invalid data; therefore this hour is based on less than 60 minutes of data.

4.2 SLURRY PIPELINE

Although no monitoring was completed in the areas where the pipeline will be located, the Fiadanana Site would be the best representation of potential noise receivers along the pipeline route.

4.3 PROCESS PLANT

4.3.1 Amboakarivo Site

Observed weather information for the 24-hour survey conducted from August 12 to August 13, 2004 is provided in Table 5.1-7. Periods of rain disturbed the program, however 18 hours and 15 minutes of data was retained and analyzed.

Table 5.1-7 Observed Weather Conditions at Amboakarivo Site

Date	Hour	Temperature [°C]	Wind Speed [m/h]	Wind Direction
August 12, 2004	9:00 AM	28	0.01	NW
August 12, 2004	9:21 AM	30	0	NW
August 12, 2004	9:40 AM	31	0	NW
August 12, 2004	2:10 PM	36	1.3	NW
August 12, 2004	3:35 PM	35	1.2	NW
August 12, 2004	11:38 PM	18	0	N/A
August 13, 2004	2:01 AM	19	0	N/A

N/A = No data collected.

Hourly L_{eq} results of the 24-hour noise survey at Amboakarivo Site are shown in Table 5.1-8. The quietest hourly L_{eq} during the monitoring period was 36.6 dBA which occurred between 3:47 AM and 4:47 AM on August 13, 2004.

Table 5.1-8 Hourly Sound Levels Recorded at Amboakarivo Site on August 12 and 13, 2004

Date	Hour	Daytime or Nighttime Period	Sound Levels [dBA]	
			L _{eq}	L _{max}
August 12, 2004	3:46 PM	daytime	42.2	66.3
August 12, 2004	4:46 PM	daytime	41.9	64.1
August 12, 2004	5:46 PM	daytime	40.3	65.6
August 12, 2004	6:46 PM	daytime	44.7	57.9
August 12, 2004	7:46 PM	daytime	48.7	64.2
August 12, 2004	8:46 PM	daytime	43.0	63.2
August 12, 2004	9:46 PM	daytime	38.8	54.5
August 12, 2004	10:46 PM ^(a)	nighttime	37.3	63.9
battery change	—	—	—	—
August 12, 2004	11:54 PM ^(a)	nighttime	39.7	53.9
Rain delay	—	—	—	—
August 13, 2004	2:01 AM ^(a)	nighttime	38.4	50.2
Rain delay	—	—	—	—
August 13, 2004	2:47 AM	nighttime	37.8	65.2
August 13, 2004	3:47 AM	nighttime	36.6	58.6
August 13, 2004	4:47 AM	nighttime	40.9	61.9
August 13, 2004	5:47 AM	nighttime	42.6	65.6
August 13, 2004	6:47 AM	nighttime	43.4	72.3
August 13, 2004	7:47 AM	daytime	39.0	58.7
August 13, 2004	8:47 AM	daytime	39.5	70.0
15-Hour Daytime	—	—	43.4	—
9-Hour Nighttime	—	—	39.4	—
24-Hour Overall	—	—	42.2	—

^(a) Measurement contains invalid data, therefore this hour is based on less than 60 minutes of data.

The average hourly L_{eq} values during the daytime and nighttime periods were 43.4 and 39.4 dBA, respectively. The main noise sources at this location are people, birds and a crew working on the school building.

The one-minute noise levels ranged between 28.3 and 52.6 dBA. Data is shown graphically in Volume I-5.1, Attachment 1 Figure 3. The graph also shows where invalid data were excluded.

4.4 TAILINGS FACILITY

4.4.1 Fiadanana Site

Observed weather information for the 24-hour survey conducted from August 13 to August 14, 2004 is provided in Table 5.1-9. Periods of rain disturbed the program, however 24 hours and 19 minutes of data was retained and analyzed.

Table 5.1-9 Observed Weather Conditions at Fiadanana Site

Date	Hour	Temperature [°C]	Wind Speed [m/h]	Wind Direction
August 13, 2004	11:46 AM	28	1.6	NW
August 13, 2004	2:00 PM	30	0	N/A
August 13, 2004	3:07 PM	39	0	N/A
August 13, 2004	3:36 PM	37	0	N/A
August 13, 2004	4:03 PM	25	0	N/A
August 13, 2004	7:51 PM	15	0	N/A
August 14, 2004	3:53 AM	15	0	N/A
August 14, 2004	8:00 AM	20	0	N/A
August 14, 2004	8:52 AM	20	0	N/A

N/A = No data collected.

Hourly L_{eq} results of the 24-hour noise survey at Fiadanana Site are shown in Table 5.1-10. The quietest hourly L_{eq} during the monitoring period was 44.9 dBA which occurred between 11:46 PM and 12:46 AM on August 13, 2004.

The average hourly L_{eq} values during the daytime and nighttime periods were 51.7 and 47.8 dBA, respectively. The noise sources that were recorded or observed come from daily activities by the villagers, people, pets and wildlife.

The one-minute revised noise levels ranged between 33.2 and 65.6 dBA. Data are shown graphically in Volume I-5.1, Attachment 1 Figure 4. The graph also shows where invalid data were excluded.

Table 5.1-10 Hourly Sound Levels Recorded at Fiadanana Site on August 13 and 14, 2004

Date	Hour	Daytime or Nighttime Period	Sound Levels [dBA]	
			L _{eq}	L _{max}
August 13, 2004	11:46 AM	daytime	51.6	70.3
August 13, 2004	12:46 PM	daytime	51.1	73.5
August 13, 2004	1:46 PM	daytime	51.0	70.7
August 13, 2004	2:46 PM	daytime	52.6	84.8
August 13, 2004	3:46 PM	daytime	52.2	83.3
August 13, 2004	4:46 PM	daytime	53.3	85.9
August 13, 2004	5:46 PM	daytime	51.9	75.3
August 13, 2004	6:46 PM	daytime	52.6	78.9
August 13, 2004	7:46 PM	daytime	49.5	69.8
August 13, 2004	8:46 PM	daytime	49.8	69.0
August 13, 2004	9:46 PM	daytime	47.2	67.1
August 13, 2004	10:46 PM	nighttime	45.2	74.0
August 13, 2004	11:46 PM	nighttime	44.9	68.3
August 14, 2004	12:46 AM	nighttime	45.6	67.1
August 14, 2004	1:46 AM	nighttime	49.4	71.0
August 14, 2004	2:46 AM	nighttime	48.1	70.2
August 14, 2004	3:46 AM	nighttime	45.8	83.7
August 14, 2004	4:46 AM	nighttime	49.8	72.0
August 14, 2004	5:46 AM	nighttime	50.0	70.5
August 14, 2004	6:46 AM	nighttime	50.8	78.2
August 14, 2004	7:46 AM ^(a)	daytime	49.6	68.4
rain delay	—	—	—	—
August 14, 2004	8:52 AM ^(a)	daytime	52.3	80.2
rain delay	—	—	—	—
August 14, 2004	9:46 AM	daytime	52.6	79.2
August 14, 2004	10:46 AM	daytime	53.1	80.1
August 14, 2004	11:46 AM	daytime	50.5	69.0
15-Hour Daytime	—	—	51.7	—
9-Hour Nighttime	—	—	47.8	—
24-Hour Overall	—	—	50.6	—

^(a) Measurement contains invalid data, therefore this hour is based on less than 60 minutes of data.

4.5 PORT SITE

Monitoring was not conducted in the urban – commercial area adjacent to the existing port area.

5 REFERENCES

World Bank. 1998. Pollution Prevention and Abatement Handbook. Toward Cleaner Production.

VOLUME I
APPENDIX 5.1
ATTACHMENT 1
NOISE GRAPHS

Figure 1 One-Minute Sound Levels at Behontsa Site

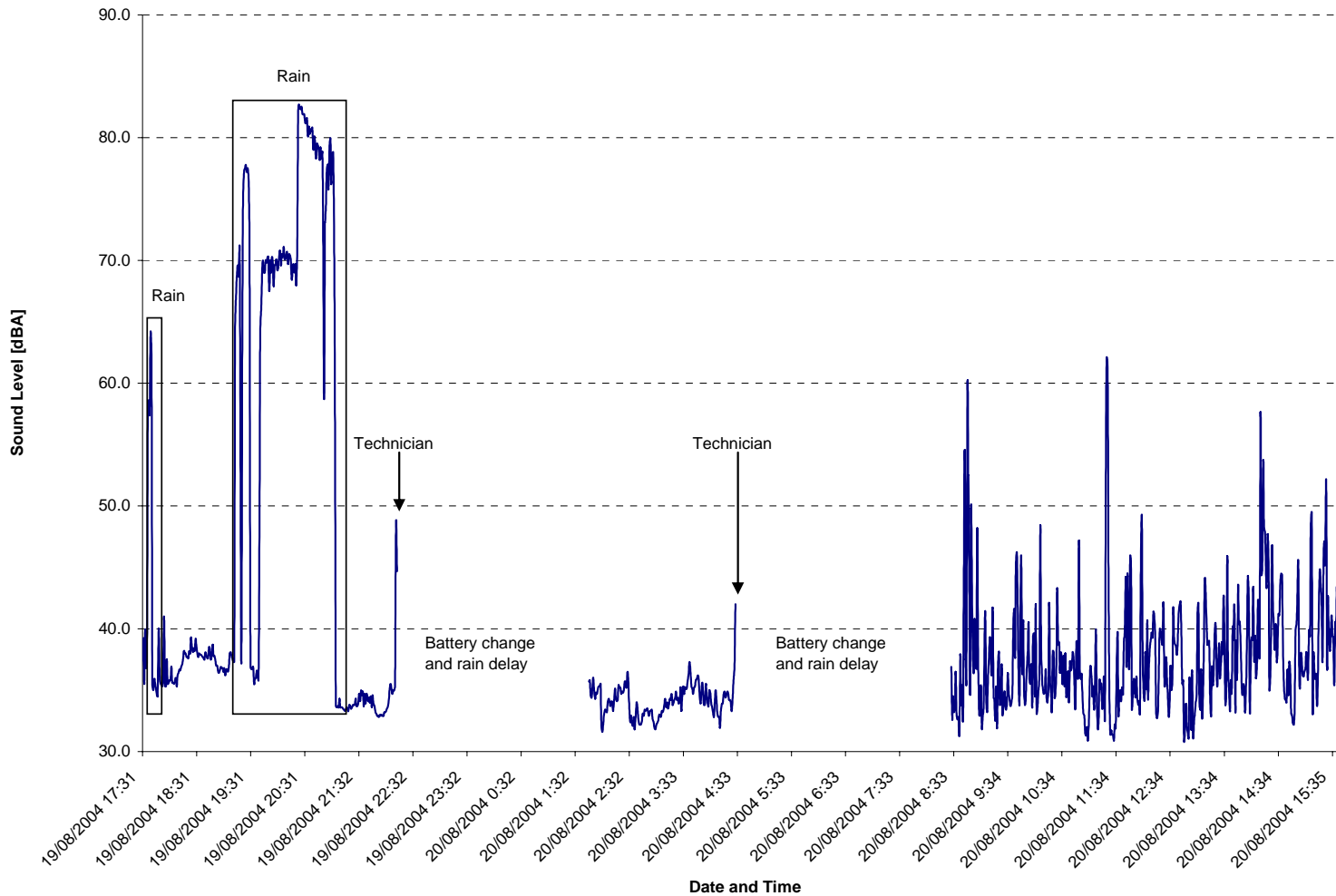


Figure 2 One-Minute Sound Levels at Berano Site

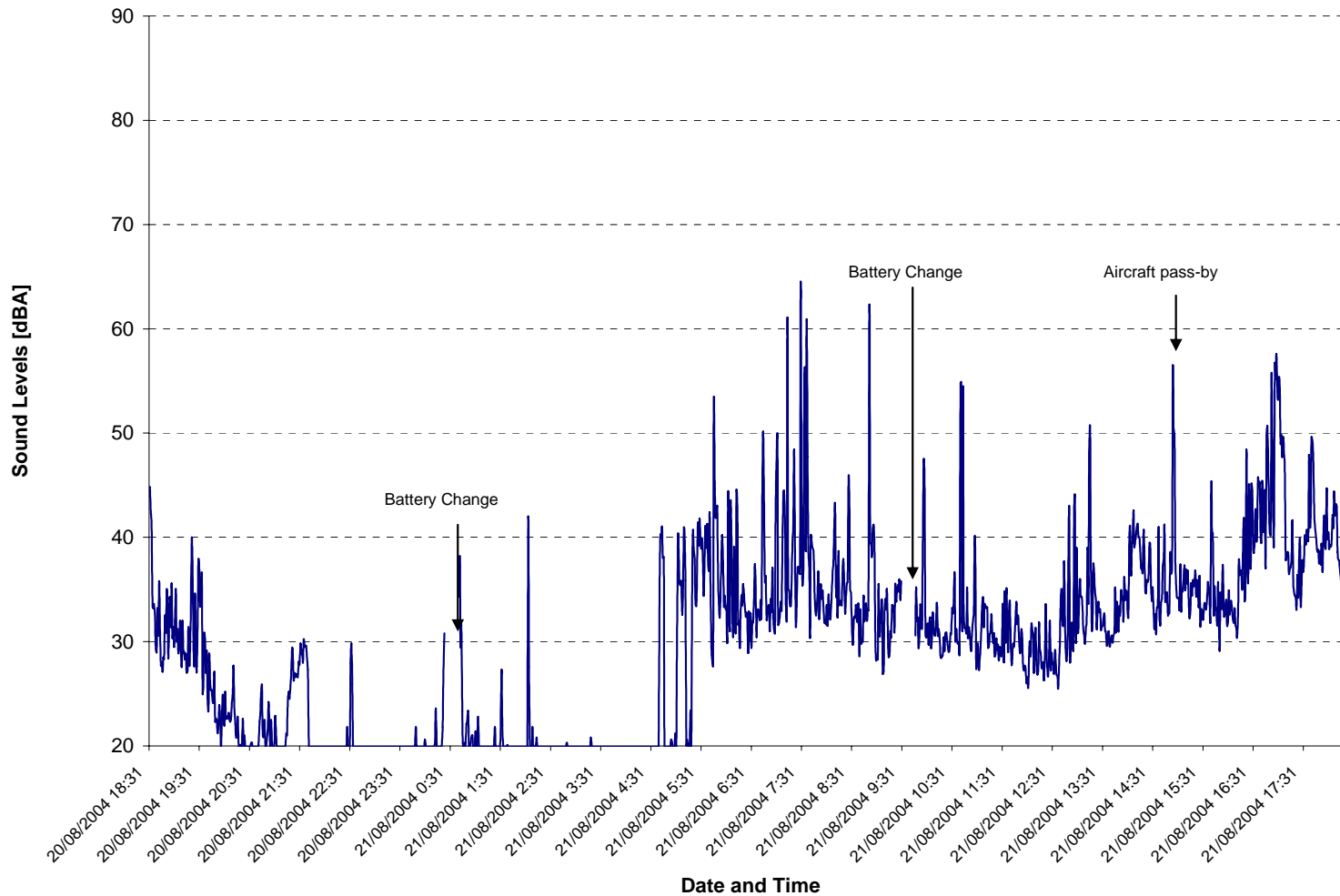


Figure 3 One-Minute Sound Levels at Amboakarivo Site

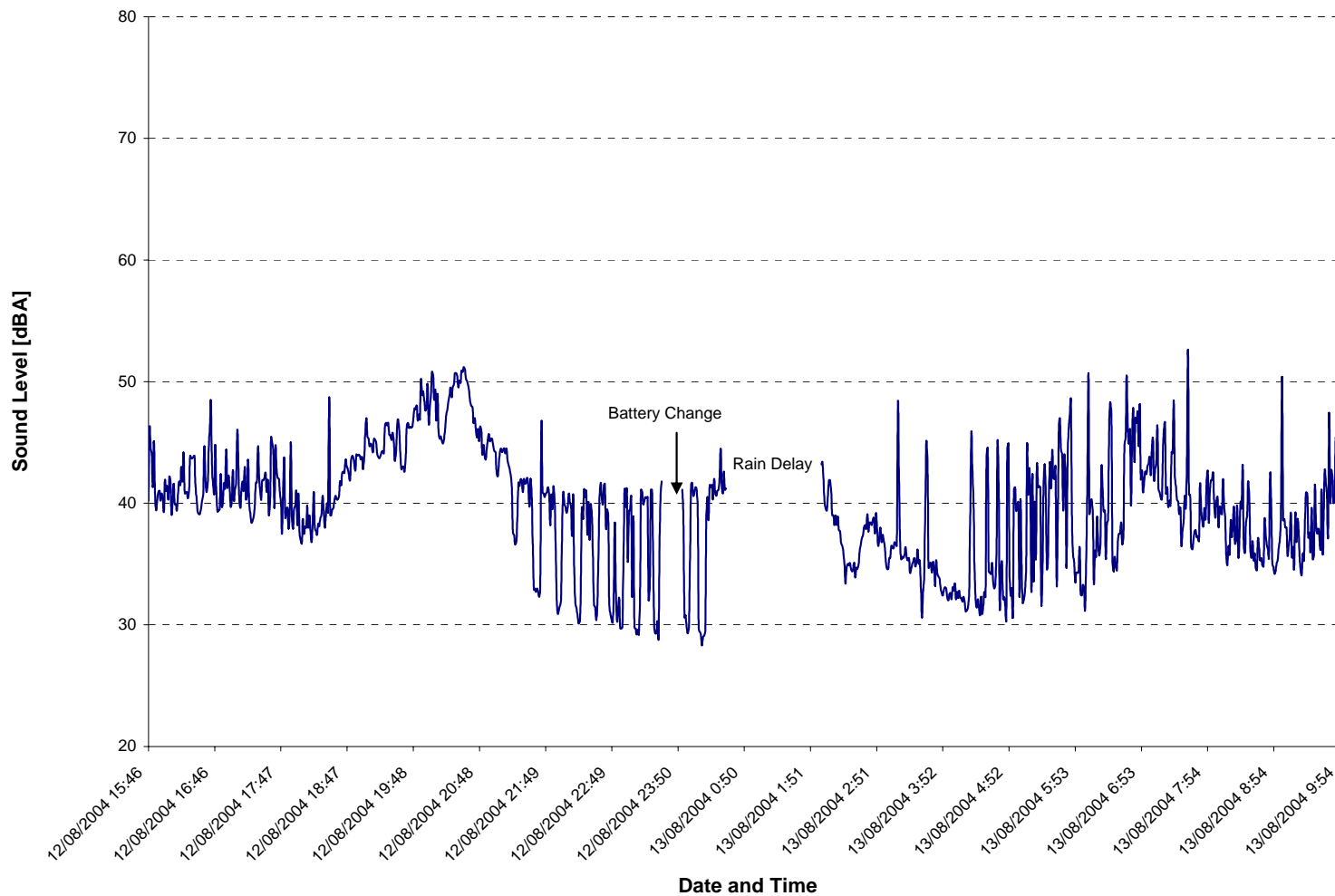
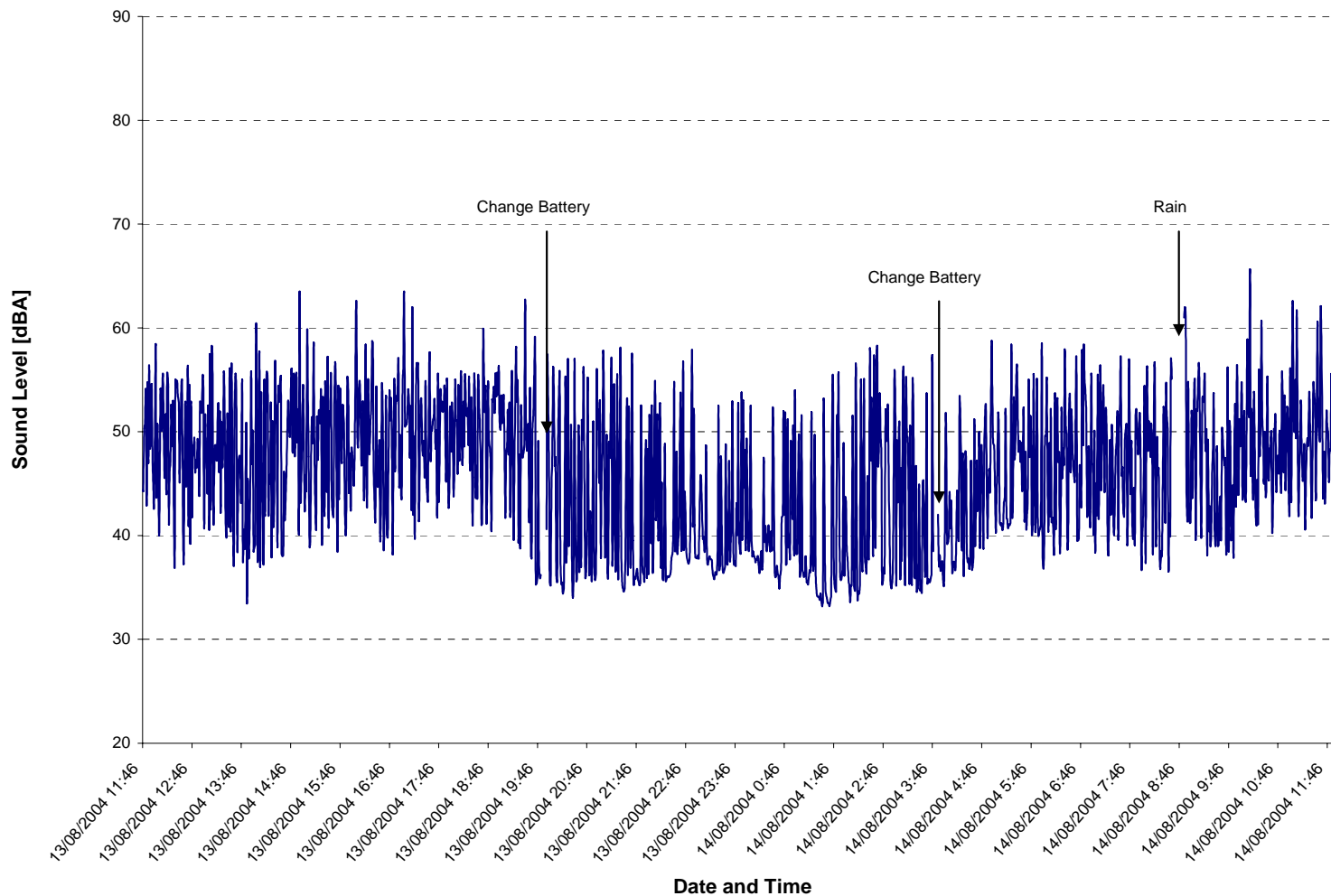


Figure 4 One-Minute Sound Levels at Fiadanana Site



VOLUME I

APPENDIX 6.1

ATTACHMENT 1

MINE NATURAL HAZARDS

**DYNATEC CORPORATION
AMBATOVY PROJECT**

**REPORT ON NATURAL HAZARDS AND
RISK ASSESSMENT FOR THE
MINE SITE
(REF. NO. NB301-00116/4-2)**

Rev. No.	Revision	Date	Approved
0	Issued to Client in Final	August 18, 2005	KDE
1	Re-issued to Client in Final	November 10, 2005	<i>WAC</i>

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DYNATEC CORPORATION
AMBATOVY PROJECT

REPORT ON NATURAL HAZARDS AND
RISK ASSESSMENT FOR THE
MINE SITE
(REF. NO. NB301-00116/4-2)

EXECUTIVE SUMMARY

This report outlines the potential natural hazards, potential consequences of failure and assessment of risk to resources downstream of the mine site. Resources downstream of the mine site that could be affected by potential natural hazards include human settlements, potable water, agricultural land and natural areas such as the Torotorfotsy Wetland.

The mine site is located on the west rim of the Ankey Range at an elevation of about 1,150 m approximately 85 km inland of the Indian Ocean and 90 km east of the capital Antananarivo. The mine site will be operated for 27 years. The initial 20 years will involve development of open pits for ore extraction and low grade ore stockpiles will be processed over the final 7 years. The processing facilities will consist of an Ore Preparation Plant which will slurry the ore and transport the slurry via a pipeline to the Plant Site located near Toamasina. Aside from the open pits, various stockpiles and waste piles will be constructed. A series of Mine Runoff Collection Ponds (Mine RCPs), each in conjunction with their own adjacent clarification pond, will be constructed to collect impacted runoff and clarify it before release to the environment. The Mine RCPs may also provide some water supply for the Ore Preparation Plant operations.

The topography of the mine area is hilly with relatively steep slopes. The mine site is located along the surface water divide between the Mangoro and Vohitra Rivers and contains the headwaters of six watersheds creating the potential for any type of failure to impact downstream resources.

A natural hazard is defined as a naturally occurring event that could lead to potential failure that would impact downslope or downstream resources. The natural hazards identified for the Ambatovy Project are generally defined as follows:

- Seismic Hazard - the potential damage occurring from an earthquake.
- Hydrological Hazard - the damage occurring from a large precipitation event or cyclone.
- Geotechnical Hazard - unforeseen geotechnical conditions could occur as an isolated event or could occur in concert with a seismic or hydrological event.

The design basis and criteria used to mitigate the natural risks defined above for the mine site are based on international standards for the design of dams to minimize risk to within recognized acceptable levels for downslope or downstream resources. In particular, all aspects of the feasibility design of the mine site infrastructure have been completed in compliance with the following three documents:

- Canadian Dam Association (CDA) Dam Safety Guidelines (CDA 1999)
- International Commission on Large Dams (ICOLD) - Tailings Dams and Seismicity - Review and Recommendations (ICOLD 1995)
- The Mining Association of Canada (MAC) Guide to the Management of Tailings Facilities (MAC 1998)

Risk is defined as the product of the probability of an event occurring multiplied by the magnitude of the consequences. On this basis, an assessment was completed to estimate the overall risk of the various hazards associated with the mine site. Given that the risk of natural hazards leading to dire consequences downstream of the mine site is considered during the design process, the risk of such an event occurring is generally very low or within normally accepted levels.

The risk assessment completed for the mine site shows that for most of the identified failure modes and consequences the overall risk falls in the Low and Extremely Low categories. Failure and subsequent consequences from a seismic event have the lowest overall risk rating, largely due to the fact that Madagascar is in a low seismic area. Potential failure and subsequent consequences due to a geotechnical issue have an overall risk mostly rated in the Extremely Low category, based on the assumption that detailed geotechnical investigations will be completed to adequately characterize conditions for a suitable detailed design to be implemented to the maximum degree possible.

For the hydrologic hazard source, for most of the failure mode and resulting consequences the overall risk ratings are evenly divided between the Extremely Low and Low categories. In general, the likelihood of a hydrologic event leading to a large discharge or failure is considered higher than a geotechnical or seismic trigger event. This is due to the fact that the mine site is located in an area prone to extreme cyclones. In addition, there is generally less understanding of precipitation or meteorological patterns than understanding of seismic and geotechnical conditions. The highest overall risk rating estimated is for heavy rains causing maximum flows over clarification pond spillways (Low category). Potential for overtopping and/or breaching of the water pond embankment due to heavy rainfalls also has a risk rating in the Low category.

Given that risk ratings are either in the Extremely Low and Low categories, further quantitative investigation of these types of risk scenarios is not required at this time.

DYNATEC CORPORATION
AMBATOVY PROJECT

REPORT ON NATURAL HAZARDS AND
RISK ASSESSMENT FOR THE
MINE SITE
(REF. NO. NB301-00116/4-2)

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AMBATOVY PROJECT

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SECTION 1.0 - SCOPE

This report outlines the potential natural hazards, potential consequences of failure and assessment of risk to resources downstream of the mine site. The project site location is shown on Figure 1.1. The mine site area is shown on Figure 1.2 while the tailings facility and plant site areas are presented on Figure 1.3. The potential natural hazards are from seismic, hydrological or geotechnical sources. Resources downstream of the mine site include small human settlements, potable water and agricultural land and natural areas such as the Torotorfotsy Wetland. The report summarizes the structures associated with the facilities at the mine site and the mitigation of risk through design by employing conservative assumptions and adhering to general international accepted standards for design. All potential failure modes are identified and the potential consequences from such failures are reviewed, both qualitatively and quantitatively.

It should be noted that only risks due to natural hazard risks have been addressed in this report. Risks associated with improper operations for the mine site should be addressed at a future phase in the project. Mitigation and management of such operating risk is usually handled through development and implementation of a proper Operations, Maintenance and Surveillance (OMS) Manual.

SECTION 2.0 - MINE SITE SETTING

2.1 LOCATION AND TOPOGRAPHY

The mine site is located on the west rim of the Ankay Range at an elevation of about 1,150 m. This location is approximately 85 km inland of the Indian Ocean and 90 km east of the capital Antananarivo, at about 18° 45' south latitude as shown on Figure 1.1. The topography of the mine area is hilly with relatively steep slopes. The mine site is close to the Mangoro River, a major north-south drainage for the region. Two ranges, Ankay to the east and L'Angavo to the west, flank the Mangoro River. The Ankay Range appears to have an important influence on the precipitation pattern of the region. Stations located near the Ankay Ridge experience more rain than stations located in the sheltered valley to the west.

As shown on Figure 1.1, the mine site is located along the surface water divide between the Mangoro and Vohitra Rivers and contains the headwaters of six watersheds. Therefore, there is potential for any type of failure to impact downstream resources. The watersheds include the Sahaviara, Antsahalava and Ankajathat that drain west towards the Mangoro River and the Sahamarinana, Torotorofotsy and Sakalava that drain east towards the Vohitra River. Portions of the area consist of a high plateau underlain by hard ferricrete substrate. The slopes around the plateau consist of weathered granular ferricrete (pisolitic ferricrete).

2.2 MINE SITE FACILITIES

The mine site will be operated for 27 years. The initial 20 years will involve development of open pits for ore extraction and low grade ore stockpiles will be processed over the final 7 years. The processing facilities will consist of an Ore Preparation Plant which will slurry the ore for transport via a pipeline to the Plant Site located near Toamasina. Aside from the open pits, various stockpiles and waste piles will be constructed. A series of Mine Runoff Collection Ponds (Mine RCPs), in conjunction with each area's own clarification pond, will be constructed to collect impacted runoff and clarify it before release to the environment. The Mine RCPs may also provide some water supply for the Ore Preparation Plant operations.

Figures 2.2 to 2.4 present plan views of the mine site at Pre-Production, Year 10 and Year 20, which is the last year of open pit mining operations. As shown on the figures, the main structures at the mine site will consist of the following:

- Open Pits Including Excavated Slopes
- Ore Preparation Plant Including Excavated Slopes
- Ambatovy Backfill Stockpiles
- Ambatovy Waste Stockpile
- Ambatovy North Mine Runoff Collection and Clarification Pond
- Ambatovy Waste Stockpile Runoff Collection and Clarification Pond
- Ambatovy South Mine Runoff Collection and Clarification Pond
- Ambatovy Southeast Backfill Runoff Collection Pond
- Low Grade Stockpiles

- Analamay Backfill Waste Stockpiles
- Analamay Waste Stockpile
- Analamay Northeast Mine Runoff Collection and Clarification Pond
- Analamay Northwest Mine Runoff Collection and Clarification Pond
- Analamay South Mine Runoff Collection and Clarification Pond

2.3 EXISTING LAND USE

The existing land use within the mine area is limited to natural forest. The dominant vegetation in the mine area comprises zonal (typical of elevation zone and climate) and azonal (atypical) natural forests consisting primarily of mid-altitude dense humid forests with variable canopy height. The azonal forest occurs on the plateau due to the ferricrete substrate. The headwater forests function as an important buffer for water quantity, releasing water even during times of drought (Golder, 1999). The forests within the mine area are relatively pristine compared to other parts of Madagascar.

The main land use in drainages downstream of the mine site consists mainly of rice cultivation.

2.4 CLIMATE

The eastern part of the island receives considerable precipitation, all in the form of rainfall, which is brought onshore by southwest trade winds. Mean annual precipitation at some locations along the eastern coast exceeds 3,000 mm. However, considerably less rainfall occurs in the central plateau. Much of Madagascar is exposed to cyclonic activity, although the east coast is most prone to severe storms. The coastal regions are generally hot throughout the year, while the central plateau has a temperate climate, with warm summers and cool winters.

Based on historical rainfall data from 8 nearby stations, the annual precipitation in the region of the mine site varies from 1,200 mm to 1,900 mm. The wet season occurs from December through March with estimated average monthly rainfall values ranging from approximately 226 mm to 338mm. The remainder of the year is much drier, with estimated monthly average rainfall values ranging from 36 mm to 138 mm. The mean annual pond evaporation is estimated to be 700 mm. Comparison of this value with annual precipitation indicates that there is a water surplus in the mine site area.

The cyclone season for Madagascar typically extends from November to April, with about 70% of the cyclones occurring from January to March. It is estimated that one major cyclone will pass over the mine area every 5 years (Phelps Dodge, 1998). Severe cyclones have impacted the mine site area in the past. For instance, Geraldo crossed the mine area between February 1 and 3, 1994, and Analamazaotra, a station 15 km from the mine site on the Ankara Ridge divide, registered 394 mm of rainfall on February 2, 1994. The maximum daily rainfall recorded at the mine site was 174.2 mm in March 2000. The maximum 24-hour rainfall values recorded for Moramanga and Perinet are 280 mm and 259.2 mm, respectively (Chaperon, et al, 1993).

2.5 SEISMICITY

The whole of Madagascar is in a region of low seismic hazard. A review of historical earthquake data for the last 25 years from the USGS National Earthquake Information Center indicates that there have been very few events recorded in or close to Madagascar. The most significant earthquake recorded in Madagascar was a Magnitude 5.3 event, located approximately 230 km northwest of the mine site. Maximum accelerations experienced at the project site would be less than 0.02 g for this event. There does not appear to be any potential for large magnitude earthquakes (Magnitude 7+) in the region.

Seismicity in southeastern Africa is generally associated with the East African Rift Zone. Normal faulting appears to characterize the scattered seismicity throughout the region between Madagascar and the eastern arm of the East African Rift Zone. The largest earthquake sequence to strike eastern Africa in the past 75 years occurred in May and June of 1985 off the coast of the Tanzania-Mozambique border, approximately 350 km northwest of Madagascar. The largest earthquake recorded in this sequence was a Magnitude 6.4 event. However, the potential seismic hazard from future events in this region is negligible as they are located over 1,000 km from the project site (Campbell, 1997).

For future design studies, it is recommended that a more detailed assessment of the regional geology and seismicity be carried out to provide a more definitive Maximum Credible Earthquake for the project site.

SECTION 3.0 - NATURAL HAZARDS AND CONSEQUENCES

3.1 GENERAL

The Canadian Dam Association (CDA) dam hazard classification selection criteria were used to determine the overall hazard potential (consequence rating) for the mine site based on the effects of a dam, waste dump or excavated slope failure. Dams and waste dumps are generally classified in accordance with the severity of hazard resulting from failure and the perceived risk of occurrence. Similar criteria are applied to excavated slopes that will be required for the open pits and Ore Preparation Plant Site. This hazard classification forms the basis for the design requirements and ongoing surveillance activities. The classification considers the potential incremental consequences of failure, which includes potential loss of life, economic damages, social and environmental impacts. The failure of a dam, waste dump or excavated slope at the mine site could lead to:

- Some fatalities
- Significant impacts in terms of socio-economic, environmental and financial factors such as loss of potable water and arable land and the cost to rebuild or relocate the local population

Therefore, the structures at the mine site are classified in the High Consequence Category.

3.2 NATURAL HAZARDS

A natural hazard is defined as a naturally occurring event that could lead to potential failure that would impact downslope or downstream resources. A natural hazard and consequence inventory has been developed for the mine site to determine potential sources of failure and potential consequences, as discussed below.

3.2.1 Seismic Hazard

The potential damage occurring from an earthquake is considered a seismic hazard. The ground motions from an earthquake could trigger the following:

- A landslide in the watersheds of the collection or clarification ponds which could cause overtopping or breaching of the embankments
- Liquefaction of the embankments and/or foundation which could cause overtopping or breaching of the embankments
- Liquefaction of the waste dump and/or excavated slopes which could cause a flow slide

3.2.2 Hydrological Hazard

A hydrological hazard is determined as the damage occurring from a large precipitation event or cyclone. The heavy rains or high winds could trigger the following:

- A landslide in the watersheds of the collection or clarification ponds which could cause overtopping or breaching of the embankments

- Inundation of the collection or clarification ponds where the overflow spillways would pass the maximum designed flows in a safe and controlled manner. This would cause flooding downstream of the mine site.
- Inundation of the collection or clarification ponds where the overflow spillways could not pass the storm flows in a safe and controlled manner. This could cause overtopping or breaching of the embankments.
- Erosion and failure of the embankments which could cause release of water to the environment
- The creation of a large wave from high winds that could overtop or breach the embankments
- Erosion and failure of the waste dumps or excavated slopes which could cause a flow slide

3.2.3 Geotechnical Hazard

Unforeseen geotechnical conditions could occur as an isolated event or could occur in concert with a seismic or hydrological event. Unforeseen geotechnical conditions could trigger the following:

- A landslide in the watersheds of the collection or clarification ponds which could cause overtopping or breaching of the embankments
- A landslide along the embankments due to poor foundation conditions, excessive seepage (piping) and/or oversteepening of the embankments that could cause overtopping or breaching of the embankments
- A landslide at the waste dumps or excavated slopes due to poor foundation conditions or oversteepening of the slopes which could cause a flow slide

SECTION 4.0 - RISK MITIGATION THROUGH DESIGN

4.1 GENERAL

The design basis and criteria for the mine site are based on international standards for the design of dams, waste dumps and excavated slopes to minimize risk to within recognized acceptable levels for downslope or downstream resources. In particular, all aspects of the feasibility design at the mine site have been completed in compliance with the following documents:

- Canadian Dam Association Dam Safety Guidelines (CDA 1999)
- International Commission on Large Dams (ICOLD) - Tailings Dams and Seismicity - Review and Recommendations (ICOLD 1995)
- The Mining Association of Canada (MAC) Guide to the Management of Tailings Facilities (MAC 1998)

As noted above in Sub-section 3.1, the consequence rating for the mine site is “High”. Selection of this consequence rating requires that the Maximum Credible Earthquake and a flood between the 1 in 1,000 year event and the Maximum Probable Flood be used for design criteria. In addition, a detailed geotechnical investigations will be required during the detailed design stage commensurate with the consequence rating.

Table 4.1 lists pertinent strategies and processes that will be employed in the design at the mine site to mitigate identified risks. It should be noted that only general design elements are presented in this document. More detailed descriptions, design parameters, analyses and structures, operational procedures and recommendations for further study are discussed in the Updated Feasibility Study Report (Knight Piésold Ref. No. NB301-116/3-2). General designs to mitigate the risk to downslope or downstream resources are discussed below.

4.2 SEISMIC DESIGN

Consistent with current design philosophy for geotechnical structures such as dams, waste dumps and excavated slopes, two levels of design earthquake should be considered as follows (ICOLD, 1995):

- Operating Basis Earthquake for normal operations
- Maximum Design Earthquake for extreme conditions

The Operating Basis Earthquake is typically determined using the probabilistic seismic hazard analysis to select an acceptable hazard level, based on the probability of exceedance over the design life of the facility. This is often chosen as the earthquake that has a 10 percent probability of exceedance in 50 years, corresponding to a return period of 475 years. Assuming a design life of 27 years, the probability of exceedance is 5.7%. The maximum acceleration for the 1 in 475 year earthquake is approximately 0.04g. The structures at the mine site would be expected to function in a normal manner after the Operating Basis Earthquake.

An appropriate Maximum Design Earthquake for the mine site has been determined based on the High consequence category. Therefore, the Maximum Design Earthquake is taken as 50 to 100% of the Maximum Credible Earthquake. A conservative design using the Maximum Credible Earthquake of Magnitude 6.0 causing a maximum acceleration of 0.16g at the project site has been determined based on the review of historical seismicity (United States Geological Service, 2005 and Global Seismic Hazard Assessment Program, 1999). Limited deformation of the embankments or waste dumps is acceptable under seismic loading from the Maximum Design Earthquake, provided overall stability and integrity is maintained and there is no release of waste or water (ICOLD, 1995).

The maximum accelerations of 0.04g and 0.16g for the Operating Basis Earthquake and Maximum Design Earthquakes, respectively, are for ground motions in bedrock or firm ground through which ground amplification effects are negligible. Maximum accelerations within the embankments or waste dumps may be higher due to amplification of ground motion through the foundation soils, embankment fills or waste.

Additional site investigations and materials testing will be completed during detailed design to confirm findings of the feasibility design. Based on the design process, the risk of failure during a seismic event will generally be extremely low due to the employment of international standards, sound research, extensive data collection and detailed analyses. In addition, the design earthquake employed is the Maximum Credible Earthquake, or the maximum earthquake that could ever happen in this region based on available seismic and tectonic information. Therefore, smaller, more frequent earthquakes will not adversely affect the mine site and operations could continue immediately following a smaller earthquake.

4.2.1 Collection and Clarification Ponds

Generalized stability models for the embankments of the collection and clarification ponds to determine the seismic stability were developed based on the designed embankment cross sections, as shown on Figure 4.1. A maximum seismic coefficient of 0.16g was adopted for the pseudo static analyses based on the Maximum Design Earthquake, as previously discussed. Results from the pseudo static stability analysis (expressed as Factor of Safety) must be greater than 1.0 to maintain stability and prevent deformation during an earthquake. All the pseudo static cases analysed met this requirement. These results indicate that under the Maximum Design Earthquake, there would be no movement or displacement of the embankments. Potential for amplification was not reviewed as part of the feasibility design but will be determined during detailed design when refined analyses are completed.

4.2.2 Waste Dumps and Excavated Slopes

The waste dumps or excavated slopes have not been designed at this stage of the project. However, detailed analyses of the waste material and soil conditions will be carried out and the waste dumps and excavated slopes will be designed to adhere to international standards against failure or unacceptable deformations during the Maximum Design Earthquake.

4.3 HYDROLOGIC DESIGN

4.3.1 Collection and Clarification Ponds

Two design storms were considered for the collection and clarification ponds as follows:

- **Environmental Design Storm** - The Environmental Design Storm is defined as the maximum 24 hour event that the collection and clarification ponds should be capable of containing prior to untreated discharge directly to the environment through an overflow spillway (South Africa, 1998). The accepted return period for an Environmental Design Storm is a 1 in 10 year event with discharge and a suspended solids concentration of 50 mg/L or less. This criterion was selected based on reviews of Madagascar effluent quality objectives and the World Bank General Criteria. As no site specific 24-hour storm event was available for the mine site area at the time of the feasibility design, a value of 250 mm for a 1 in 10 year 24-hour event was used for the Environmental Design Storm. A more accurate value may be adopted during detailed design if additional information is available and assessed.
- **Inflow Design Flood** - The Inflow Design Flood for a facility with a High consequence rating is the resulting flood between the 1 in 1,000 year precipitation event and Probable Maximum Flood. Therefore, the Probable Maximum Flood has been used in the design. The collection and clarification ponds will need to be capable of passing the Probable Maximum Flood in a safe and controlled manner through adequately sized overflow spillways to protect the embankments from overtopping and breaching. The Probable Maximum Flood is based on the Probable Maximum Precipitation event with a duration that causes the maximum peak flow through the overflow spillway. In order to estimate the Probable Maximum Precipitation for the mine site area, precipitation data from Analamazaotra was reviewed. Analamazaotra is located approximately 15 km southeast of the mine site on the Ankara Ridge divide. Based on this assessment, a 12-hour Probable Maximum Precipitation of 1,500 mm as well as corresponding values for shorter durations have been adopted for design of the overflow spillways.

The collection and clarification ponds have been designed to contain the Environmental Design Storm above the Normal Maximum Operating Level and below the spillway invert elevation. In addition, the ponds will be able to safely pass an Inflow Design Flood equivalent to the Probable Maximum Precipitation. Therefore, sufficient freeboard (wet freeboard) must be provided above the Environmental Design Storm level to pass the Probable Maximum Precipitation through a suitably sized overflow spillway. In addition, freeboard above the Inflow Design Flood maximum flood level (dry freeboard) will be provided to handle wave run-up during a cyclone (Mitchell, 1983).

Based on the analyses carried out from the feasibility design, the Inflow Design Flood will result in peak pond outflows from approximately 460 to 1,760 m³/s. Therefore, spillway

widths of up to 232 m with peak depths of up to 4.4 m will pass these flows in a safe and controlled manner.

The Probable Maximum Flood used in this analysis does not have a return period, as it is assumed that the rainfall from this storm is the absolute highest. Therefore, storms with return periods will be smaller than the design storm which assures that the spillways will pass these storm flows in a safe and controlled manner. By selecting the Probable Maximum Flood for design of storm routing measures, the risk of overtopping the embankment during a storm event generally be extremely low.

4.3.2 Waste Dumps and Excavated Slopes

The hydrologic designs for the waste dumps and excavated slopes have not been completed at this time. However, it is envisioned that the design will include adequate drainage measures to pass storm flows in a safe and controlled manner. Preliminary plans and sections on Figure 4.2 present the design components, as follows:

- Bench Design: The benches of the waste dumps and excavated slopes will be graded to channel water to the edge of the waste dump.
- Ditch Design: Ditches at the edge of the waste dumps and excavated slopes will collect runoff from the individual benches and transfer the runoff to the collection ponds.
- Vegetation Design: Vegetation will be established on the waste dump and excavated slope benches and slopes to minimize erosion.

4.4 GEOTECHNICAL DESIGN

Embankments, waste dumps and excavated slopes will be constructed at the locations shown on Figures 2.2 through 2.4. All embankments will be constructed using the downstream method, while all waste dumps and excavated slopes will be constructed using a series of benches until the ultimate design height is reached.

Additional site investigations and materials testing will be completed during detailed design to confirm and optimize findings of the feasibility design. Based on the design process, the risk of failure due to a geotechnical flaw will be very minimal due to the employment of international standards, sound research, extensive data collection and detailed analyses. In addition, international standards for Factor of Safety (i.e. 1.5) will be followed using conservative material parameters to ensure that the design is adequate.

4.4.1 Collection and Clarification Ponds

The proposed cross sections for the embankments at the collection and clarification ponds consist of an upstream zone of select fill (weathered gabbro) and a downstream zone of local random fill, which may consist of weathered gabbro but may include ferrallite or other suitable materials.

A vertical chimney drain (sand filter zone) is located between the upstream and downstream zones. The chimney drain will collect any seepage through the upstream zone, while ensuring that internal stability is maintained by preventing the migration of particles to the downstream zone. A blanket drain system will collect seepage from embankment and foundation units. This will minimize pore pressures in the embankment and foundation. The drains will also enhance embankment stability by ensuring that the phreatic surface is maintained at low levels within the foundation and downstream embankment zone.

The embankments will act as overflow structures due to the large storm flows. Therefore, the crests and downstream slopes will be armoured with concrete covered gabion mats.

Instrumentation, such as piezometers, slope inclinometers, monitoring wells and flow weirs, will be installed in the foundations, embankments and downstream of the embankments. Regular monitoring of the instrumentation will be completed and annual reviews will be carried out by a suitably qualified person to evaluate the performance of the ponds and to recommend any necessary remedial actions. Appropriate trigger levels for alerting personnel of potential danger will be set for the instrumentation.

Generalized stability models were developed based on the embankment cross sections and materials described above. The required Factor of Safety for the long-term static case, as recommended by the CDA, is 1.5 and all analysed cases met this criteria. The short term period following construction of the initial embankments (when high pore pressures may exist within the embankment fill) will be evaluated as part of the detailed design for the project, when more data is available. This case will consider the undrained strength of the fill.

4.4.2 Waste Dumps and Excavated Slopes

Detailed analyses will be carried out to determine the geotechnical characteristics of the various overburden and foundation materials and the waste dumps and excavated slopes will be designed to international standards against failure.

SECTION 5.0 - RISK ASSESSMENT

5.1 GENERAL

Risk is defined as the product of the probability of an event occurring multiplied by the magnitude of the consequences. In order to determine if a risk is acceptable, an assessment is required to estimate the overall risk by considering the likelihood of an event occurring and the magnitude of the consequences. As it is difficult to quantify in numerical terms probability and magnitude, a relative risk ranking or rating scheme is usually employed.

As discussed, the risk of natural hazards leading to a failure at the mine site thereby leading to dire consequences downstream is considered in the design process. Through application of internationally accepted design criteria and analyses, the risk of such an event occurring will be very low or within normally accepted levels. The risk mitigation through design needs to be taken into account when assessing the likelihood of occurrence.

Following completion of a relative risk assessment, more thorough analysis of the highest risk events may be completed. This usually involves modelling the identified failure process to estimate the resultant consequences so that the magnitude can be quantified. Depending on the level of risk, measures may be taken to remove or minimize it. In some cases, minimizing the risk may be as simple as the development of an Emergency Response Plan to evacuate people should a failure start to develop.

The sub-sections below summarize the methodology and results of the relative risk assessment completed for the mine site to identify higher risk events.

5.2 RELATIVE RISK ASSESSMENT

Table 5.1 summarizes the relative ranking scheme that has been employed for conducting a relative or subjective risk assessment for the mine site. As shown on Table 5.1, five ranking categories have been used to rank Likelihood of Occurrence (Probability) and Magnitude of Consequences. Numerical values from 1 to 5 have been applied to the categories with the higher number representing higher likelihood of occurrence or magnitude of consequences. A general definition has been included for each of the ranking categories and levels. Five overall risk ranges have been specified based on the highest potential product of Likelihood of Occurrence multiplied by Magnitude of Consequences.

The ranking scheme on Table 5.1 has been applied to the identified failure modes and consequences summarized on Table 4.1. The results are presented on Table 5.2 and discussed below.

In terms of what is acceptable for Overall Risk Rating, the Extremely Low category is the best outcome. The Low category is considered acceptable although further work may be required to further understand the risk and develop further mitigation measures. An Overall Risk Rating that is in the Moderate category or higher requires additional study and completion of a mitigation plan.

The overall risk ratings, presented on Table 5.2, for all of the identified failure modes and consequences, falls in the Low and Extremely Low categories. Failure and subsequent consequences from a seismic event have the lowest overall risk rating. This is largely due to the fact that Madagascar is in a low seismic area and that application of conservative seismic design parameters will address seismic concerns. Potential failure and subsequent consequences due to geotechnical issues have an overall risk rating in the Extremely Low category with the exception of one that rated in the low range of the Low category. This is based on the assumption that detailed geotechnical investigations will be completed to adequately characterize conditions for a suitable detailed design. Adequate geotechnical characterization and design will ensure that the probability of a large scale failure and massive release of sediment laden water will be very low. The probability of a small scale failure leading to embankment damage or a small release of sediment laden water is slightly higher due to the possibility of smaller geological features being missed.

For the hydrologic hazard source, for five of the failure mode and resulting consequences, the overall risk rating falls in the Extremely Low category and five results fall in the lower range of the Low category. In general, the likelihood of a hydrologic event is considered higher than a geotechnical or seismic event. This is due to the fact that the mine site is located in an area prone to extreme cyclones. In addition, there is generally less understanding of precipitation or meteorological patterns than understanding of seismic and geotechnical conditions. The highest overall risk rating estimated is for heavy rains causing maximum flows over the spillways (Low category). Potential for overtopping and/or breaching of the embankments due to heavy rainfalls also has a risk rating in the Low category.

All overall risk ratings are either in the Extremely Low and Low categories. Therefore, further quantitative investigation of these types of risk scenarios is not required at this time.


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SECTION 7.0 - CERTIFICATION

This report was prepared, reviewed and approved by the undersigned.

Prepared by:


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Senior Engineer



Reviewed by:


M. Parfitt, P.Eng.
Project Manager

Approved by:


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Managing Director

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TABLE 4.1

DYNATEC CORPORATION
AMBATOVY PROJECT

REPORT ON NATURAL HAZARDS AND RISK ASSESSMENT FOR THE MINE SITE

NATURAL HAZARD AND CONSEQUENCE INVENTORY

Natural Hazard Source	Failure Mode (Hazard Outcome)	Consequence	Risk Mitigation through Design
1.0 Seismic	1.1 Earthquake causing landslide in watershed	a) Overtopping of embankments causing release of sediment laden water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway
		b) Breach of embankments causing release of sediment laden water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway
	1.2 Earthquake causing liquefaction of embankments	a) Overtopping of embankments causing release of sediment laden water to the environment	Detailed, state-of-the-art geotechnical testing of fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, design earthquake ground motions and deformations, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)
		b) Breach of embankments causing release of sediment laden water to the environment	Detailed, state-of-the-art geotechnical testing of tailings, fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, design earthquake ground motions and deformations, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)
	1.3 Earthquake causing liquefaction of waste dump	a) Flow slide	Detailed, state-of-the-art geotechnical testing of waste overburden and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, design earthquake ground motions and deformations
2.0 Hydrologic	2.1 Heavy rain causing landslide in watershed	a) Overtopping of embankments causing release of sediment laden water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway
		b) Breach of embankments causing release of sediment laden water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway
	2.2 Heavy rain causing maximum flows over spillway	a) Flooding and damage to downstream resources	Conservative selection of design storm (PMP), inundation studies, storm routing design, spillway design, embankment freeboard
	2.3 Heavy rain causing inundation of embankments	a) Overtopping of embankments causing release of sediment laden water to the environment	Conservative selection of design storm (PMP), inundation studies, storm routing design, spillway design, embankment freeboard
		b) Breach of embankments causing release of sediment laden water to the environment	Conservative selection of design storm (PMP), inundation studies, storm routing design, spillway design, embankment freeboard
	2.4 High winds causing large waves at embankments	a) Overtopping of embankments causing release of sediment laden water to the environment	Conservative selection of design wind (200 km/h), spillway design, embankment freeboard
		b) Breach of embankments causing release of sediment laden water to the environment	Conservative selection of design wind (200 km/h), spillway design, embankment freeboard
	2.5 Heavy rain causing erosion and failure of waste dump	a) Flow slide	Detailed, state-of-the-art geotechnical testing of waste overburden and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, drainage design
	2.6 Heavy rain causing erosion and failure of embankments	a) Minor slump leading to temporary release of sediment laden water to the environment	Detailed, state-of-the-art geotechnical testing of fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)
		b) Major slump leading to loss of freeboard and breach of embankment causing release of sediment laden water to the environment	Detailed, state-of-the-art geotechnical testing of fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)
3.0 Geotechnical	3.1 Poor geotechnical conditions causing landslide in watershed	a) Overtopping of embankments causing release of sediment laden water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway
		b) Breach of embankments causing release of sediment laden water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway
	3.2 Poor, unforeseen foundation or fill conditions causing embankment failure	a) Minor slump leading to temporary release of sediment laden water to the environment	Detailed, state-of-the-art geotechnical testing of fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)
		b) Major slump leading to loss of freeboard and breach of embankments causing release of sediment laden water to the environment	Detailed, state-of-the-art geotechnical testing of fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)
	3.3 Poor, unforeseen foundation or fill conditions causing waste dump failure	a) Flow slide	Detailed, state-of-the-art geotechnical testing of waste overburden and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety

TABLE 5.1

DYNATEC CORPORATION
AMBATOVY PROJECT

REPORT ON NATURAL HAZARDS AND RISK ASSESSMENT FOR THE MINE SITE

RELATIVE RANKING SCHEME

Ranking Categories	Likelihood of Occurrence (Probability)		Magnitude of Consequences		Overall Risk
Extremely Low	1	Negligible chance of occurrence, <1:10,000 yr "doubt it will ever happen"	1	No fatalities possible, minor to no damages beyond owners property	1 - 4
Low	2	Not likely to occur, 1:1,000 to 1:10,000 yr "highly unlikely to happen"	2	No fatalities anticipated, minor damages beyond owners property	5 - 8
Moderate	3	Moderate frequency of occurrence, 1:100 to 1:1,000 yr "it could happen"	3	No fatalities anticipated, Moderate property damages	9 - 14
High	4	Frequent occurrences, 1:10 to 1:100 yr "it has happened, or it probably will happen"	4	Some fatalities possible, Large property damages	15 - 19
Extremely High	5	Very frequent occurrences, >1:10 yr "happens all the time"	5	Large number of fatalities possible, Extreme property damages	20 - 25

I:\301-00116-4\Assignment\Report\Report 2, Rev. 1\Table 5.1 - Subjective Ranking Scheme.xls]Table 5.1

14-Nov-05

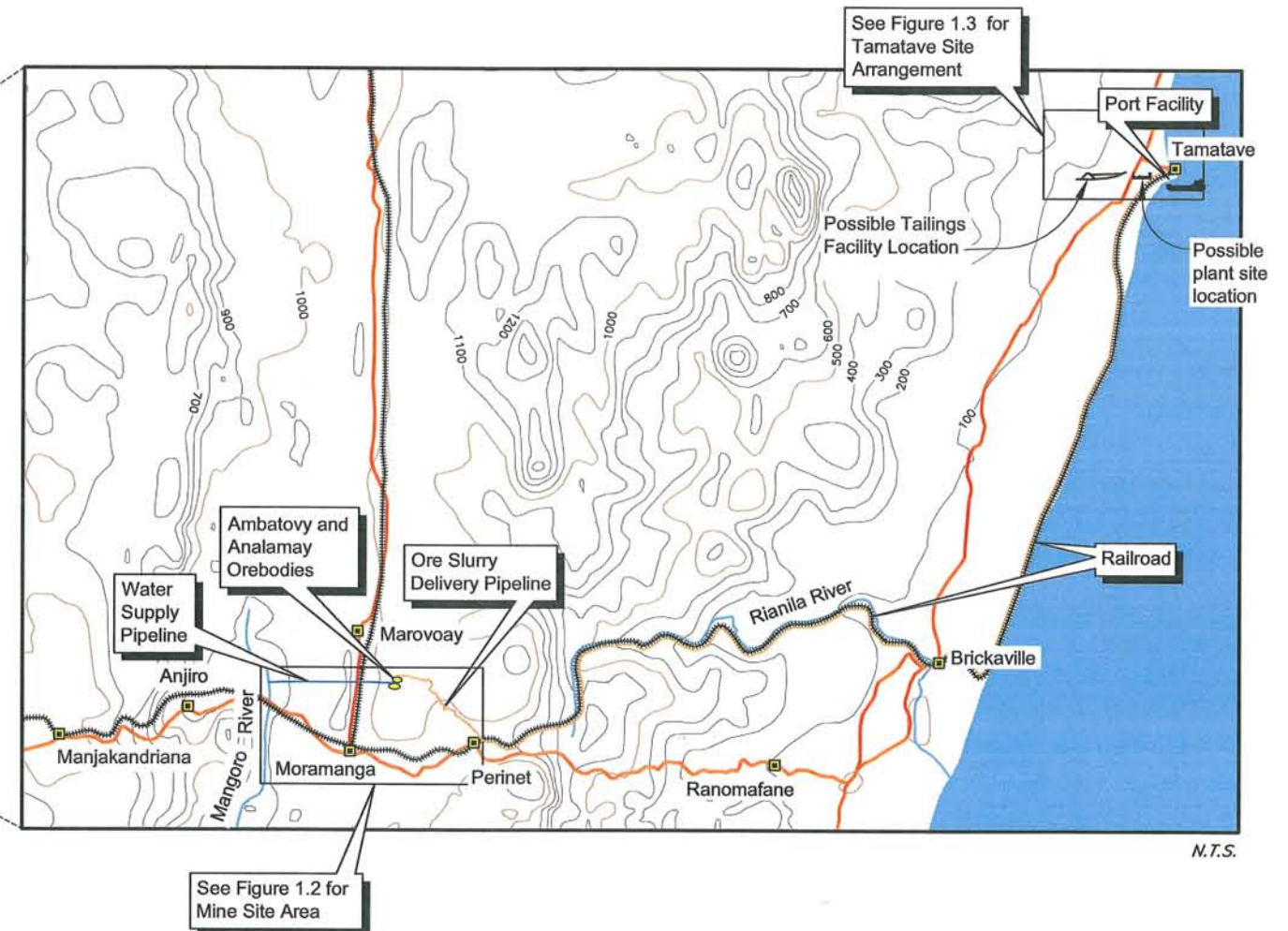
Note:

1. Ranking Category "Extremely Low" signifies negligible occurrence potential.
2. Details above adapted from Pelletier and Dushnisky (1993) and Davies (1998).

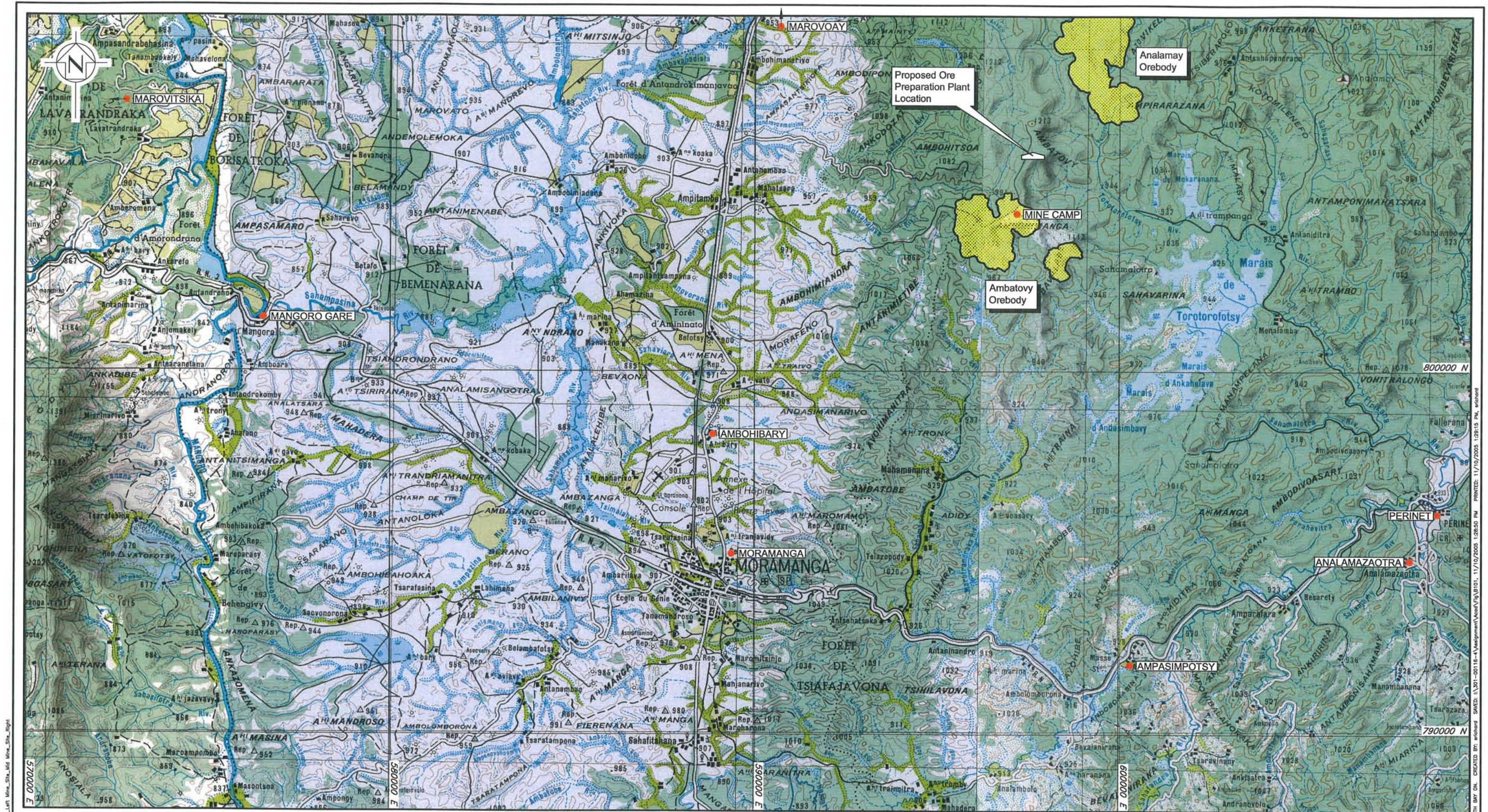
TABLE 5.2
DYNATEC CORPORATION
AMBATOVY PROJECT
REPORT ON NATURAL HAZARDS AND RISK ASSESSMENT FOR THE MINE SITE
RELATIVE RISK ASSESSMENT SUMMARY

Natural Hazard Source	Failure Mode (Hazard Outcome)	Consequence	Risk Mitigation through Design	Likelihood of Occurrence Ranking	Consequence Ranking	Overall Risk Rating
1.0 Seismic	1.1 Earthquake causing landslide in watershed	a) Overtopping of embankments causing release of sediment laden water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway	2	2	4
		b) Breach of embankments causing release of sediment laden water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway	1	3	3
	1.2 Earthquake causing liquefaction of embankments	a) Overtopping of embankments causing release of sediment laden water to the environment	Detailed, state-of-the-art geotechnical testing of fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, design earthquake ground motions and deformations, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)	1	2	2
		b) Breach of embankments causing release of sediment laden water to the environment	Detailed, state-of-the-art geotechnical testing of fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, design earthquake ground motions and deformations, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)	1	3	3
	1.3 Earthquake causing liquefaction of waste dump	a) Flow slide	Detailed, state-of-the-art geotechnical testing of waste overburden and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, design earthquake ground motions and deformations	1	1	1
2.0 Hydrologic	2.1 Heavy rain causing landslide in watershed	a) Overtopping of embankments causing release of sediment laden water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway	2	2	4
		b) Breach of embankments causing release of sediment laden water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway	1	4	4
	2.2 Heavy rain causing maximum flows over spillway	a) Flooding and damage to downstream resources	Conservative selection of design storm (PMP), inundation studies, storm routing design, spillway design, embankment freeboard	3	2	6
	2.3 Heavy rain causing inundation of embankments	a) Overtopping of embankments causing release of sediment laden water to the environment	Conservative selection of design storm (PMP), inundation studies, storm routing design, spillway design, embankment freeboard	2	3	6
		b) Breach of embankments causing release of sediment laden water to the environment	Conservative selection of design storm (PMP), inundation studies, storm routing design, spillway design, embankment freeboard	1	5	5
	2.4 High winds causing large waves at embankment	a) Overtopping of embankments causing release of sediment laden water to the environment	Conservative selection of design wind (200 km/h), spillway design, embankment freeboard	2	2	4
		b) Breach of embankments causing release of sediment laden water to the environment	Conservative selection of design wind (200 km/h), spillway design, embankment freeboard	1	5	5
	2.5 Heavy rain causing erosion and failure of waste dump	a) Flow slide	Detailed, state-of-the-art geotechnical testing of waste overburden and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, drainage design	2	2	4
	2.6 Heavy rain causing erosion and failure of embankments	a) Minor slump leading to temporary release of sediment laden water to the environment	Detailed, state-of-the-art geotechnical testing of fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)	2	2	4
		b) Major slump leading to loss of freeboard and breach of embankment causing release of sediment laden water to the environment	Detailed, state-of-the-art geotechnical testing of fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)	1	5	5
3.0 Geotechnical	3.1 Poor geotechnical conditions causing landslide in watershed	a) Overtopping of embankments causing release of sediment laden water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway	2	2	4
		b) Breach of embankments causing release of sediment laden water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway	1	3	3
	3.2 Poor, unforeseen foundation or fill conditions causing embankment failure	a) Minor slump leading to temporary release of sediment laden water to the environment	Detailed, state-of-the-art geotechnical testing of fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)	2	2	4
		b) Major slump leading to loss of freeboard and breach of embankments causing release of sediment laden water to the environment	Detailed, state-of-the-art geotechnical testing of fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)	1	5	5
	3.3 Poor, unforeseen foundation or fill conditions causing waste dump failure	a) Flow slide	Detailed, state-of-the-art geotechnical testing of waste overburden and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety	2	2	4

I:\301-00116-4\Assignment\Report\Report 2, Rev. 1\Table 4.1, Table 5.2.xls]Table 5.2
14-Nov-05



Dynatec DYNATEC CORPORATION			
AMBATOVY PROJECT			
PROJECT SITE LOCATION			
Knight Piésold CONSULTING	P/A NO. NB301-00116/4	REF. 2	REV. 0
	FIGURE 1.1		



LEGEND:

- Water
- Orebody
- Rain Gauge

NOTES:

1. Based on 1:100,000 FTM Topographic Map Nos U47, U46, T46 and T47.

1000 0 1000 2000 3000 4000 5000 Metres
Scale

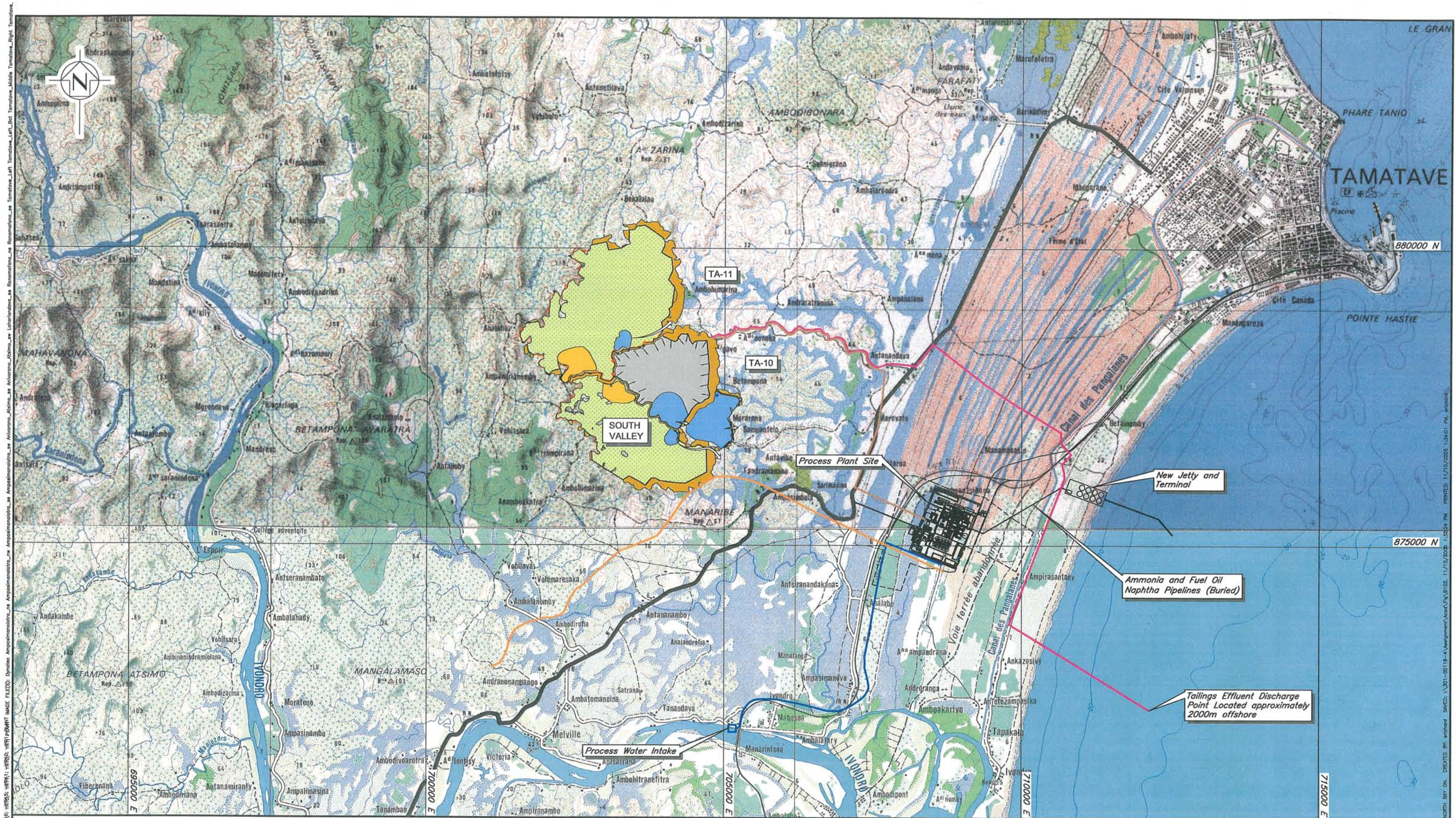
Dynatec DYNATEC CORPORATION

AMBATOVY PROJECT

MINE SITE AREA
REGIONAL PLAN

Knight Piésold
CONSULTING

P/A NO. NB301-00116/4	REF. 2	REV. 0
FIGURE 1.2		



LEGEND:

Water
RN-2
Tailings effluent pipeline

Tailings slurry pipeline
Ore slurry pipeline
Process water supply pipeline

Tailings Beach
Embankment
Topsoil Stockpile
Reclaimed Tailings Beach

NOTES:

1. Based on 1:50,000 FTM Topographic Map No. V45.
2. Tailings facility shown represents configuration at end of year 20 of operations.

Scale 600 0 600 1200 1800 2400 3000 Metres

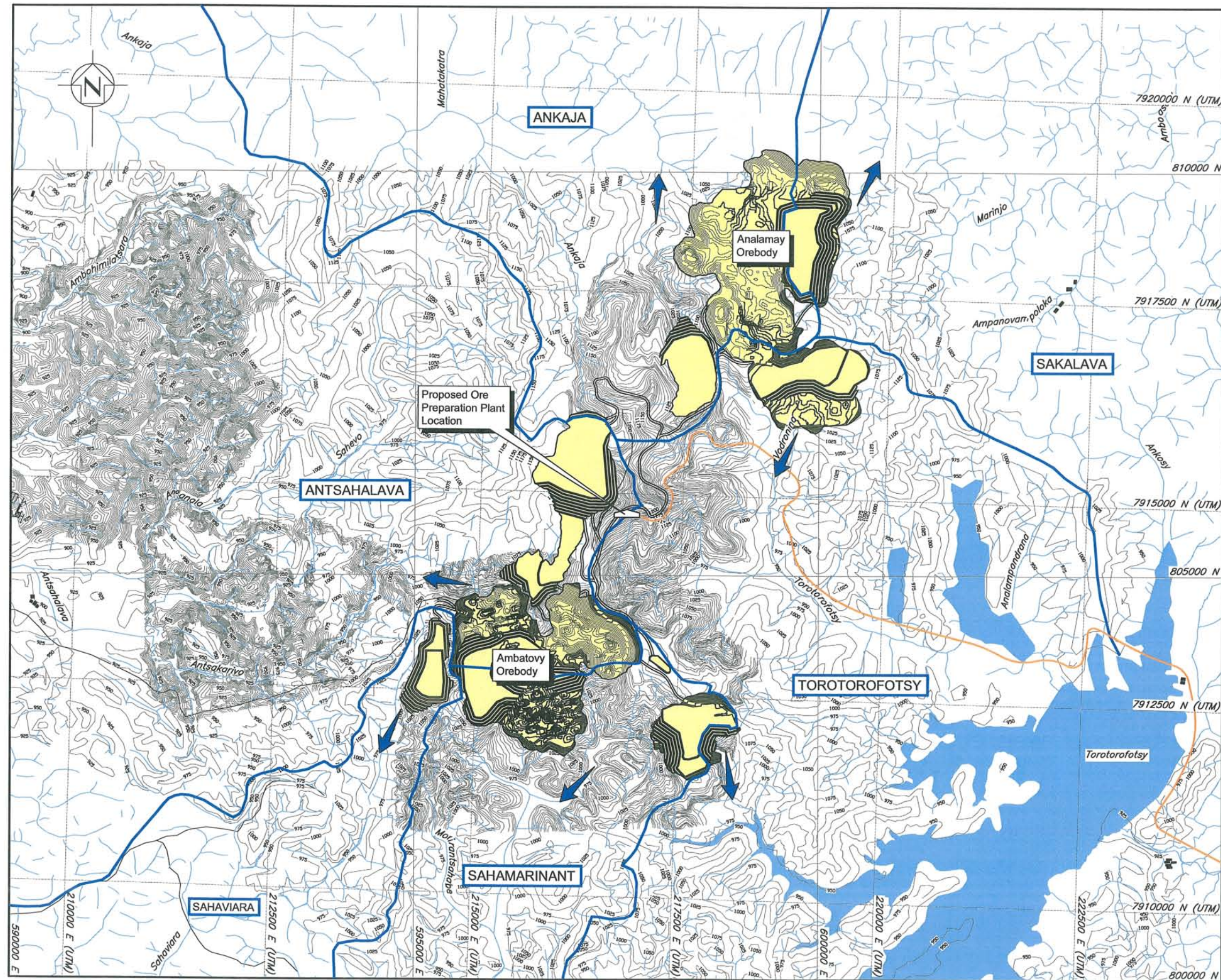
Dynatec DYNATEC CORPORATION

AMBATOVY PROJECT

TAILINGS AND PLANT SITE AREA
PLAN

Knight Piésold
CONSULTING

P/A NO. NB301-00116/4	REF. 2	REV. 0
FIGURE 1.3		



LEGEND:

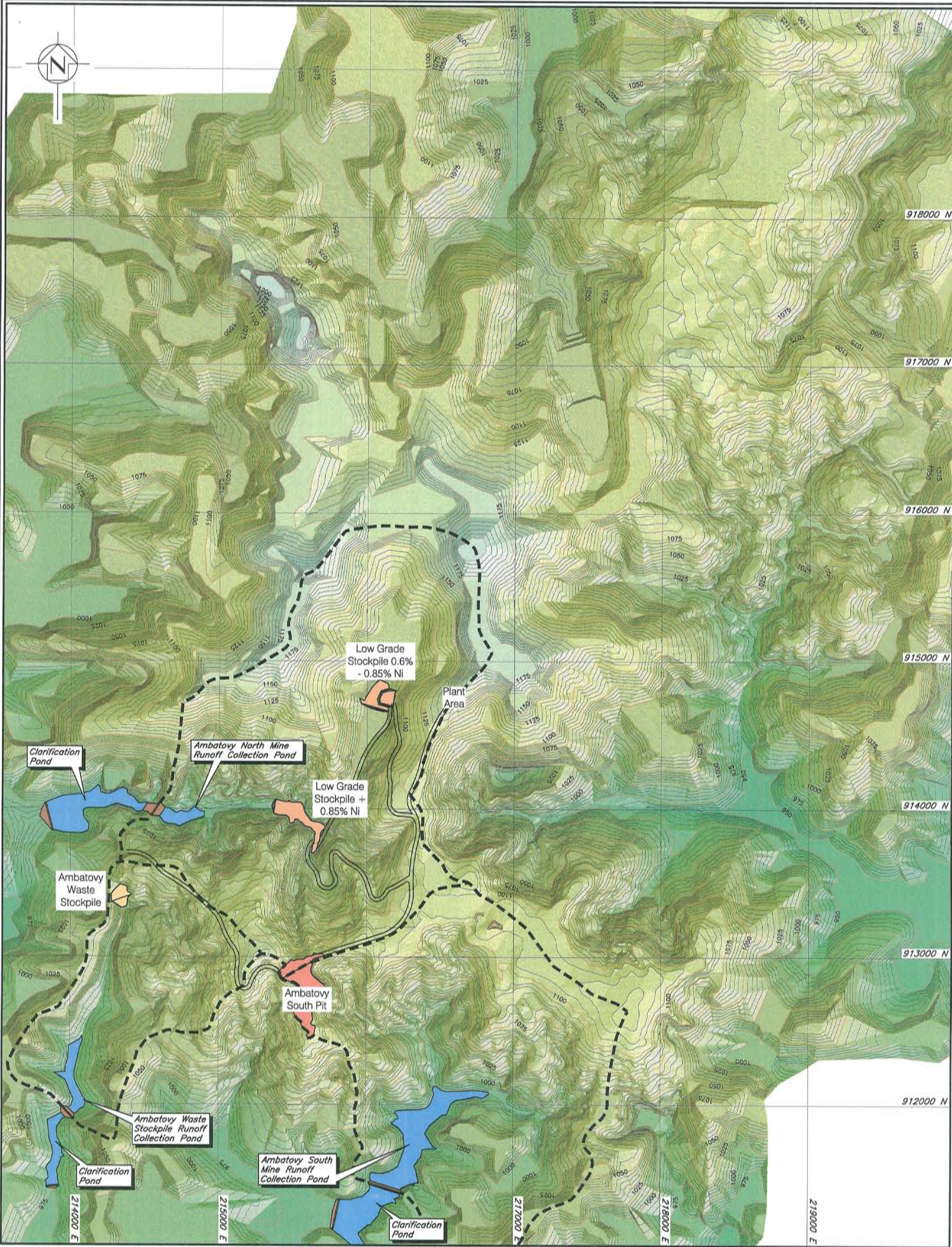
- Water/Wetland
- Mining Activity
- River/Stream
- Road
- Watershed Boundary
- Ore Delivery Pipeline
- Drainage course receiving mine runoff

NOTES:

1. Topography and hydrology features provided by Golder Associates and preliminary mine features provided by Murray and Roberts.
2. Elevations shown are metres above sea level.
3. Grid is Laborde system with UTM overlay.

Scale 500 250 0 500 1000 1500 2000 2500 Metres

Dynatex DYNATEC CORPORATION			
AMBATOVY PROJECT			
MINE SITE BASE PLAN WATERSHED AREAS			
	P/A NO.	REF.	REV.
	NB301-00116/4	2	1
FIGURE 2.1			



LEGEND:

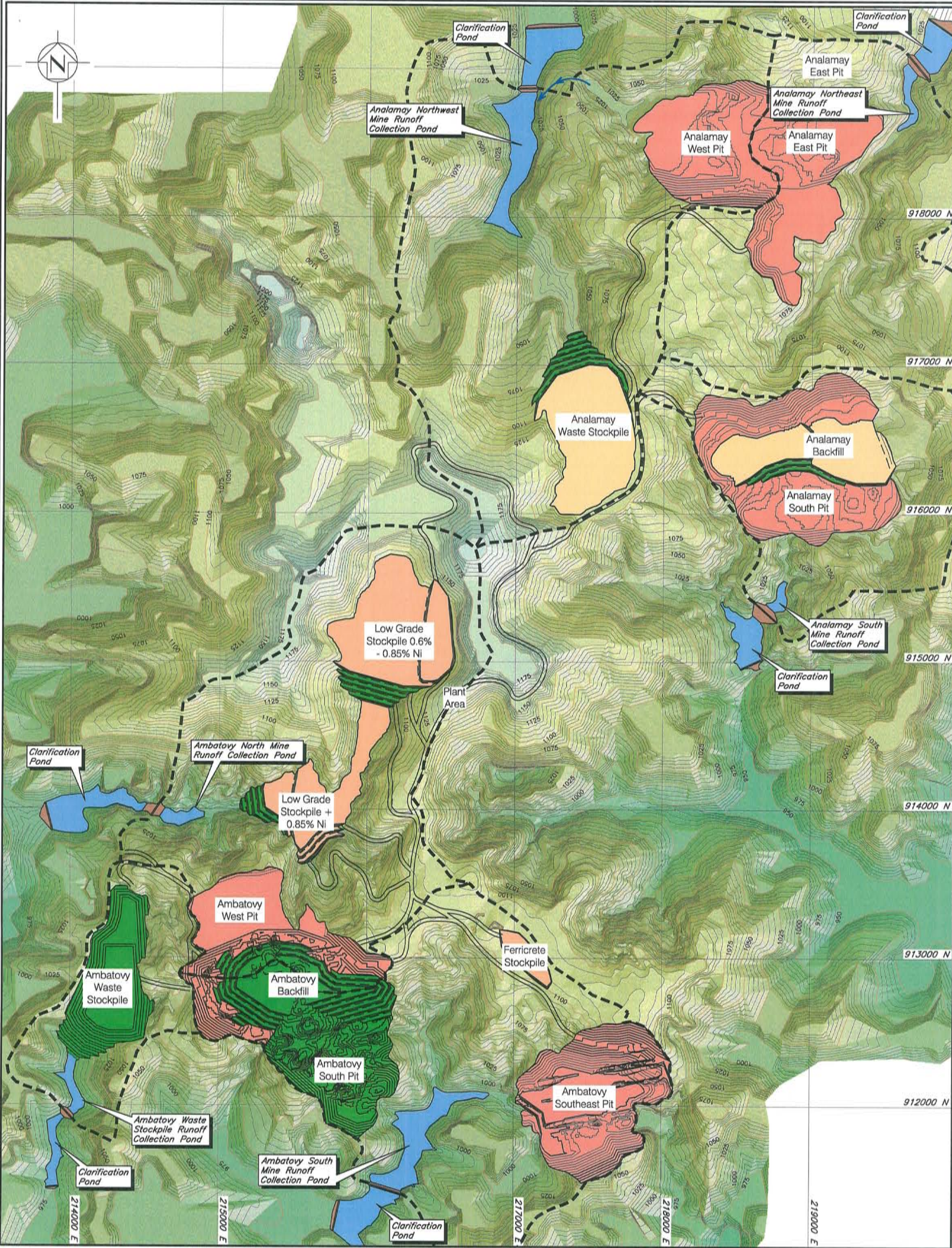
- | | |
|------------------------|------------------------|
| Approximate Pond Area | Active Waste Dump Area |
| Active Mining Area | Rehabilitated Area |
| Active Stockpile Area | |
| ----- Watershed Divide | |

NOTES:







1. Topography and mine plan layout shown provided by IMC dated Sept. 29, 2004, and represents pre-production.
2. Coordinates are in UTM.
3. Contour interval is 5m.
4. Limits of ponds and embankments are approximate and may change.

Scale 250 0 250 500 750 1000 1250 Metres

DYNATEC CORPORATION	
AMBATOVY PROJECT	
MINE AREA LAYOUT PRE-PRODUCTION	
Knight Piesold CONSULTING	P/A NO. NB301-00116/4
	REF. 2
FIGURE 2.2	



LEGEND:

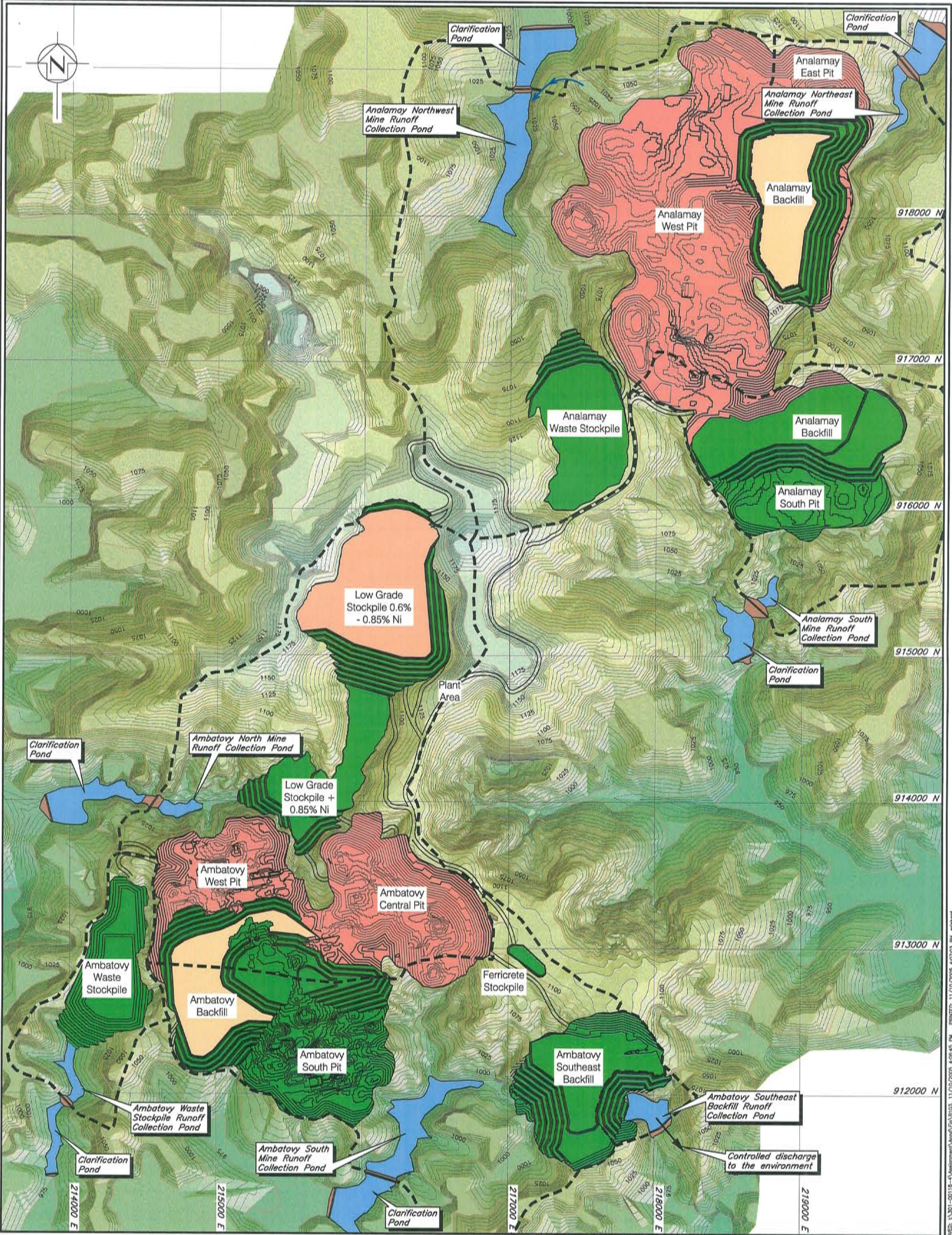
- | | |
|---|--|
|  Approximate Pond Area |  Active Waste Dump Area |
|  Active Mining Area |  Rehabilitated Area |
|  Active Stockpile Area | |
|  Watershed Divide | |

NOTES:






1. Topography and mine plan layout shown provided by IMC dated Sept. 29, 2004, and represents Year 10.
2. Coordinates are in UTM.
3. Contour interval is 5m.
4. Limits of ponds and embankments are approximate and may change.



DYNATEC CORPORATION	
AMBATOVY PROJECT	
MINE AREA LAYOUT YEAR 10	
Knight Piésold CONSULTING	P/A NO. NB301-00116/4
	REF. 2
FIGURE 2.3	



LEGEND:

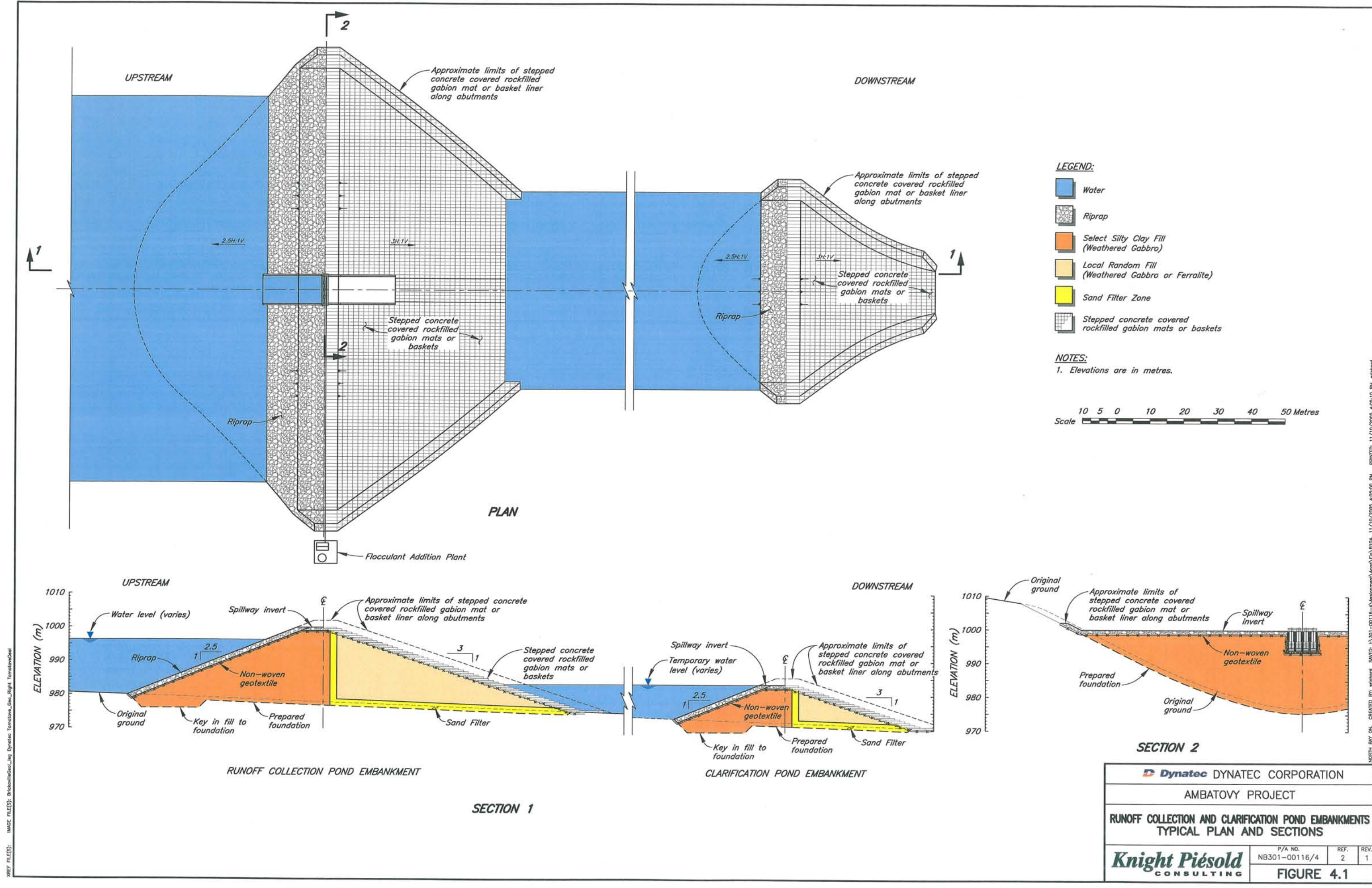
- | | |
|---|--|
|  Approximate Pond Area |  Active Waste Dump Area |
|  Active Mining Area |  Rehabilitated Area |
|  Active Stockpile Area | |
| ----- Watershed Divide | |

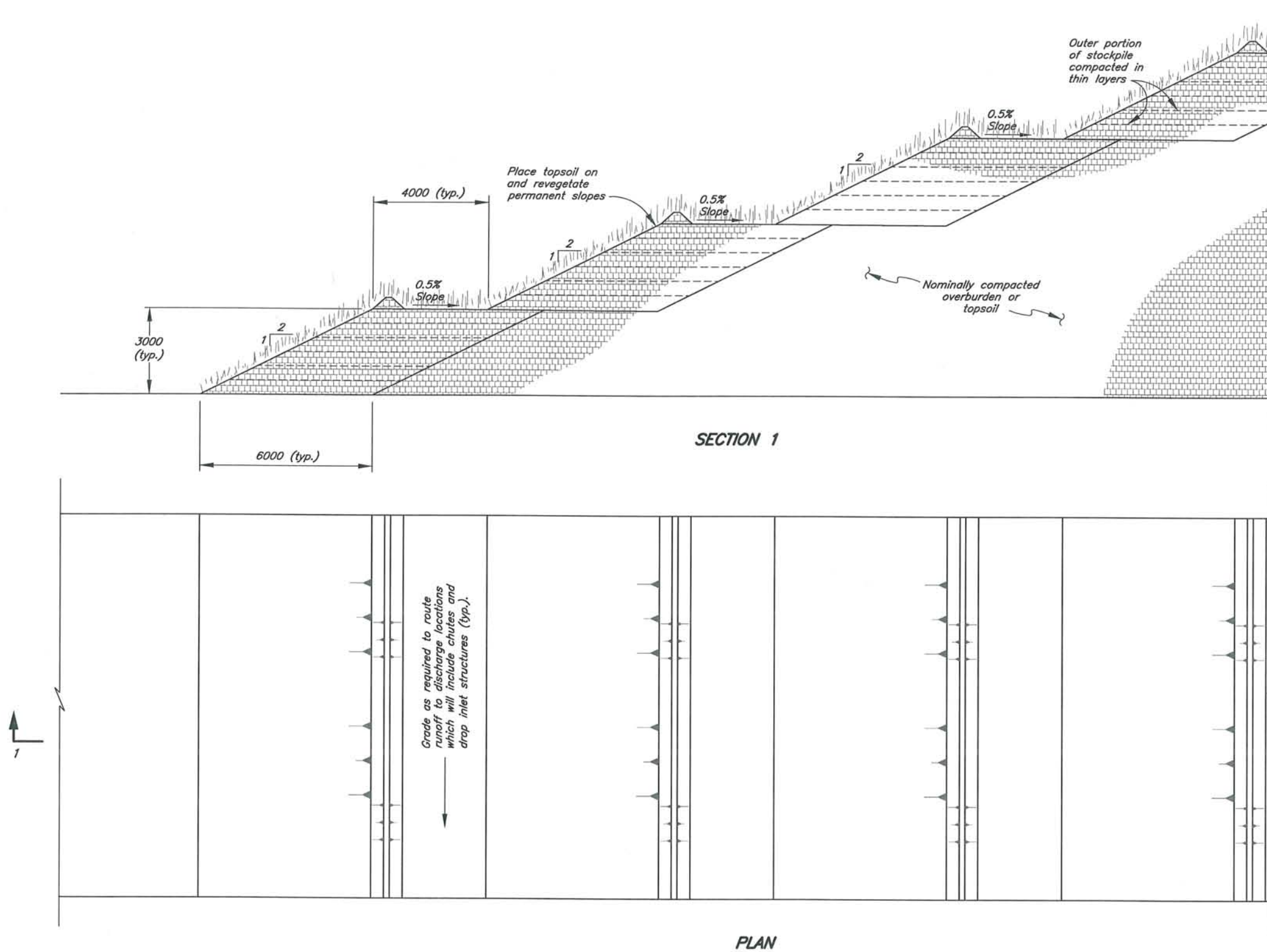
NOTES:

1. Topography and mine plan layout shown provided by IMC dated Sept. 29, 2004, and represents Year 20.
2. Coordinates are in UTM.
3. Contour interval is 5m.
4. Limits of ponds and embankments are approximate and may change.



Scale 250 0 250 500 750 1000 1250 Metres

DYNATEC CORPORATION	
AMBATOVY PROJECT	
MINE AREA LAYOUT YEAR 20	
Knight Piésold CONSULTING	P/A NO. NB301-00116/4
	REF. 2
FIGURE 2.4	







LEGEND:

-  Nominally compacted fill
-  Lifts

NOTES:

1. All dimensions are in millimetres unless otherwise noted.

 DYNATEC CORPORATION			
AMBATOVOY PROJECT			
CONSTRUCTED STOCKPILE SLOPES TYPICAL PLAN AND SECTION			
	P/A NO. NB301-00116/4	REF. 2	REV. 0
	FIGURE 4.2		

VOLUME I

APPENDIX 6.1

ATTACHMENT 2

PIPELINE NATURAL HAZARDS



Pipeline Systems Incorporated

5099 Commercial Circle, Ste. 102, Concord, CA 94520 USA

www.pipesys.com

DYNATEC CORPORATION

AMBATOVY NICKEL – LATERITE PIPELINE PROJECT

PIPELINE SYSTEM NATURAL RISKS REPORT

PSI Document No.: 1114-G-006

B	<i>16-Mar-05</i>	Integration with EA	<i>WJN</i>	<i>WJN</i>	S.Penttinen
A	12-Mar-05	Initial Review	WJN	WJN	S. Penttinen
Rev.	Date	Revision	By	PSI Approved	Client Approved



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1.0 INTRODUCTION

Golder Associates Ltd. (Golder) is completing an environmental assessment (EA) for Dynatec Corporation (Dynatec) on the Ambatovy Nickel Laterite project in Madagascar. Pipeline Systems Incorporated (PSI) previously completed a feasibility level design and cost estimate for the ~195 kilometer (km) ore slurry pipeline that is part of the project configuration (see PSI document 1114-G-005).

As part of assessing risks to the project facilities, Golder is reviewing natural risks and the potential impact. Dynatec has requested PSI summarize the potential impacts to the ore slurry pipeline and efforts to mitigate the impacts that have been incorporated into the project design. This summary will support the EA initiatives relative to natural risks for the pipeline.

2.0 GENERAL PIPELINE SAFETY

Long term safe and reliable operation of a slurry pipeline begins in the design phase and continues through ongoing pipeline operations. Application of proven design practices and development of project-specific safety systems ensures this reliability can be achieved. Commercially operating slurry pipelines have provided reliable service without environmental impact in high earthquake zones (Chile and Peru), extremely wet environments (Brazil), and in remote regions (China and Australia).

The proposed Ambatovy slurry pipeline does not present unique conditions for which successful pipeline designs have not been achieved. In all aspects, the pipeline is within commercially proven limits.

2.1 Route Selection

The selected route and developed design for the Ambatovy pipeline mitigate the risk of damage to the pipeline during operations (and thus, the potential for damage to the land along the right-of-way). The following strategies have been implemented for this project:

- The selected route is generally located away from human activity. Failure data on operating pipelines suggests that third party actions (accidental or sabotage) cause the greatest number and largest pipeline failures. The selected route is generally away from inhabited areas and will deviate around any small villages encountered.
- The pipeline will be installed below ground. Operating experience for pipelines of all types indicates that buried pipelines are less susceptible to mechanical damage. Weather events (cyclones, tornados, lightening, etc.) and surface disturbances (landslides, earthquakes, etc.) present less risk of damage to a buried pipeline than one installed on the surface.
- Special attention will be paid to the geo-technical selection and design of the pipeline right-of-way. The route will be selected to avoid geo-technically unstable areas wherever possible – special designs will be applied to the pipeline if a geo-technical risk (geo-hazard) exists.
- In sensitive areas such as at river or road crossings, within inhabited zones, etc., a deeper burial depth and/or thicker pipe will be considered to mitigate the risk of damage. This design is particularly effective in river crossings where the pipe can be buried below the “worst case” scour event.



2.2 Pipeline Design

The proposed Ambatovy slurry pipeline will be designed, constructed, operated and maintained in accordance with ASME B31.11 – “Slurry Transportation Pipeline Systems”. This code has been applied to other slurry pipelines around the world and provides proven guidelines which ensure pipeline safety. This code imposes appropriate safety factors are applied during the design phase.

The pipeline design will be completed by a knowledgeable, experienced, specialty pipeline engineering company. This team will ensure proper application of all design guidelines (such as the ASME code), and also will apply lessons learned from other commercial pipeline operations. Use of an experienced design team will result in a state-of-the-art pipeline system.

2.3 Safety Systems

The primary operational risk of damage to a slurry pipeline is over-pressure of the pipeline due to system malfunction or operating error (human error). To ensure the pipeline is not overstressed and no damage (or breakage) occurs, the pipeline will be equipped with an over-pressure protection system using rupture discs. Rupture discs are mechanical devices which do not require power, controls, or any other support system to function – this ensures the “safety system” is always engaged regardless of the facility status.

There are two points at which pipeline blockage could occur – the intermediate valve station and the terminal station. Each site will be equipped with a rupture disc. The intermediate valve station will utilize a “cascade” design. The terminal station rupture disc will discharge into the slurry receiving tank at the terminal.

The cascade design means that if the pipe upstream of the valve station should have high pressure and burst the rupture disc, the rupture disc will discharge into the pipeline downstream of the valve station. If the terminal valves are open, the pipe will continue to flow into the tank. If the terminal valves are closed, the terminal rupture disc will also likely burst. Use of this cascade design at the intermediate valve station ensures that no slurry is spilled at this site. All slurry will be contained within the mainline pipe during a rupture disc release.

There is usually some worry that the slurry pipeline could “plug” with solids. This is an unreasonable fear when considering the pipeline design and commercial operating experience. The solids represent only ~20% of the volume in the slurry being transported (~40% of the weight). The slope of the installed pipeline is limited to ensure the solids will settle in place if flow is stopped. This ensures that the pipeline cross-section can not be filled with solids.



PSI laboratory testing indicates that the Ambatovy slurry particles are relatively fine and settle very softly in comparison to other commercial operations. Other systems with higher operating volume percents have more than 30 years of operating history without pipeline plugs. These systems have experienced long term shutdowns (more than 5 days) without restart problems. There is no reasonable cause to believe the Ambatovy pipeline will plug with solids.

Historical data on pipelines of all types indicates that third party intervention (purposeful and accidental) is the primary cause of pipeline failures and leaks. As noted above, the selected pipeline route for Ambatovy will be routed away from areas of human activities wherever possible. To ensure rapid operator response to an unexpected event, the pipeline will be equipped with a state-of-the-art control system including a leak detection system. Early detection of a pipeline leak ensures rapid response and minimizes the risk of environmental impact. The leak detection system is described in Section 4 below.



3.0 PIPELINE NATURAL RISKS

The following sections summarize possible risks to the pipeline, efforts to mitigate these risks, and comments from other commercial operating experience. It should be noted that all the pipeline design standards applied to slurry pipelines are also used for oil and gas pipelines where the consequence of failure is more significant due to the flammable nature of the material that could leak. These designs have been commercially proven to mitigate the risk of pipeline failure.

3.1 Leakage Due to Corrosion or Wear

3.1.1 Description

Pipeline damage can occur due to internal corrosion and erosion as well as due to external corrosion. Loss of pipe wall thickness due to these phenomena can lead to failure and a slurry leak result.

The failure type and size are somewhat dependent on the mechanism causing the metal loss – it can be as small as a pinhole leak in the line up to a pipeline rupture due to thinning pipe that can not contain the operating pressure. If a pinhole leak occurs, the erosive nature of the high-velocity, escaping slurry will quickly enlarge the hole increasing the leak volume. A small leak in a slurry pipeline typically does not stay small for very long.

3.1.2 Mitigation

3.1.2.1 Internal Corrosion

Commercial operating data from other unlined, steel slurry pipelines indicates that the quality of the process water used to make the slurry is the primary determinant in the corrosion potential. The source water for Ambatovy is run-off rain water collected at site supplemented by the Mangoro River– the water quality data supplied to PSI indicates that the corrosion potential from this water is low (see PSI document 1114-G-H-001). The low corrosion potential also indicates that pH changes will not materially impact pipeline corrosion.

Pipeline operating data also shows that dissolved oxygen is directly linked to corrosion potential. For unlined steel pipelines, the dissolved oxygen is often consumed by the pipeline in the first few kilometers such that the corrosion is localized in this section.

The pipeline metal loss rate is expected to be less than 0.05 millimeters per year (2 mils per year) due to corrosion from the process water. This could be twice as high in the first 5 to 10 kilometers due to dissolved oxygen in the water. The Ambatovy



pipeline was designed for 0.20 mm/yr (8 mils per year) for the first ten kilometers and 0.10 mm/yr (4 mils per year) for the remainder of the pipeline.

3.1.2.2 Internal Erosion

Commercial operating data for slurry pipelines demonstrates that several factors can contribute to pipeline metal loss, such as operating velocity, particle size distribution, slurry pH, water quality, and dissolved oxygen content. It is often difficult to differentiate the corrosion and erosion components. PSI has found that the following key factors determine the erosion potential:

- Particle size distribution
- Specific Gravity of solids (weight of the particles)
- Operating velocity

Evaluation of slurry samples from Ambatovy indicates that the portion of coarse solids is low, the viscosity (from the percent fines) is high, and the operating velocity is low. This indicates that the pipeline wear rate will be negligible. A comparison to the SAMARCO iron concentrate pipeline is provided in the table below.

Parameter	Ambatovy	SAMARCO
Material	Nickel Laterite	Iron Concentrate
Pipe diameter	22-inch	20-inch
Pipeline length	~195 km	~400 km
Material	Unlined steel	Unlined steel
Particle size (D80)	48 to 58 microns	45 to 50 microns
SG of solids	3.6 to 3.8	4.9 to 5.0
Operating viscosity	11.43 @ 40 wt%	11.43 @ 68 wt%
Concentration range	40 to 45 wt%	65 to 72 wt%
Operating velocity	1.56 to 1.90 m/s	1.75 to 2.25 m/s
Year installed	Future	1977

The water source for SAMARCO is river water (as is Ambatovy). The operating conditions at SAMARCO mirror those proposed at Ambatovy – Ambatovy particles are slightly coarser but SAMARCO particles are slightly heavier. SAMARCO operating velocities are generally higher than those proposed at Ambatovy.

SAMARCO has operated for more than 25 years and actively monitored pipeline metal loss rates over this period. Total pipe metal loss rates are generally less than 0.05 mm/yr (2 mils per year) except in the first 10 km of the pipeline where metal loss rates are about 0.13 mm/yr (5 mils per year). As noted above, the Ambatovy



pipeline was designed for 0.20 mm/yr (8 mils per year) for the first ten kilometers and 0.10 mm/yr (4 mils per year) for the remainder of the pipeline.

3.1.2.3 External Corrosion

External corrosion of the pipe is determined by the soil conditions along the route. During detailed engineering, route investigations will be made to measure this potential (soil resistivity). A specific design will be developed to prevent external corrosion.

The pipe will be installed with an external fusion bonded epoxy coating as primary protection against external corrosion. Commercial experience with similar coating systems suggest a 30+ year life can be reasonably expected. The coating system will be supplemented with an impressed current cathodic protection system. The cathodic protection system includes sacrificial anodes that will corrode over the project life. Regular system monitoring will indicate if the anodes need replacement – this is likely the only maintenance activity required to achieve a 30+ year life.

Commercial operating experience indicates that a high-quality external pipe coating in combination with a cathodic protection system will provide reliable long-term protection against external corrosion.

3.1.3 Other Comments

Two similar commercial operations provide worthwhile benchmarks against the proposed Ambatovy system – the SAMARCO iron concentrate pipeline in Brazil (discussed above) and the Disputada copper ore transport system in Chile.

The SAMARCO system operates in a very similar environment to the proposed Ambatovy system. The pipeline was installed in 1977 with a 20-year design life. SAMARCO has actively monitored the pipe wall thickness throughout the life of the project. Metal loss has been below the original design such that the original pipeline is expected to last about 30 years. PSI is now in the process of designing the first replacement section (about 20 km of the total 400 km length). With this strategic replacement, the pipeline is expected to continue operating for 5 to 10 more years when the next section will be replaced.

The Disputada copper ore slurry pipeline was initially installed in 1987. It was a 55 km long, 20-inch diameter unlined steel pipeline that included more than 3,000 meters of elevation drop. The copper ore slurry is much coarser than the Ambatovy slurry and the operating velocity is maintained at more than 2.5 m/s. As such, the pipeline was originally installed with the expectation that it would wear out (internal erosion).



Like SAMARCO, Disputada regularly monitors pipeline metal loss. The original design considered a 10 year life based on the installed erosion allowance. The first replacement section was installed in 1998 and the last section (pipeline replacement is now complete) was installed in 2004. The new pipeline is 24-inch diameter and has a 12 year design life.

At both SAMARCO and Disputada, actual pipe metal loss rates were proven to be less than the original design. The same methodology was used to conservatively select the initial wall thickness for Ambatovy. At both SAMARCO and Disputada, routine collection of wall thickness data is a proven predictor of pipeline life with no premature failures having resulted. The same inspection methods are anticipated to be used at Ambatovy – the inspection results will validate the original design assumptions or identify that mitigation efforts are required.

Commercial operating experience suggests that the risk of failure by corrosion or wear is low.

3.2 Breakage Due to Land Slide

3.2.1 Description

Pipeline damage can occur if a land slide or land slip should occur along the pipeline route. A land slide would comprise material above the pipeline right-of-way sliding down on top of the pipeline right-of-way potentially damaging the pipeline platform and the pipeline route. A land slip would comprise movement of the land containing the pipeline platform and pipeline. Either movement, if large enough, could cause a pipe failure.

3.2.2 Mitigation

During the detailed engineering phase of the project, a geo-technical investigation will be made along the entire pipeline route. The objective of the investigation is to select a route through which a stable pipeline “platform” can be developed. This platform will be used for construction and contains the trench for pipeline burial. The final route selection seeks to avoid areas of high risk.

The major risk of damage to a pipeline is land slip – i.e., failure of the pipeline platform. The route optimization/selection will seek mature, stable geo-technical structure to minimize the risk of slip. The following additional designs will be implemented:

- The pipeline will always be installed on the uphill side/shoulder of the pipeline platform ensuring maximum distance from the natural surface.



- Special attention will be paid to natural water drainage for the land above the pipeline platform to ensure no blockage. Culverts and other water diversion structures will be utilized to provide drainage and prevent saturation of the earth containing the pipeline.
- The pipeline will only be installed in natural, cut soil – it will not be installed in fill material which could fail more easily than mature soils.
- Erosion control measures including reseeding, water diversion, geo-textiles, etc. will be used along the pipeline platform to prevent damage after the completion of construction.

Of secondary concern to a buried pipeline is a land slide. Application of the design features listed above results in an installation that provides ample resistance to land slide damage. The pipeline platform absorbs the primary impact of a land slide – maintaining a stable platform mitigates damage to the pipeline. Installation of the pipeline in the uphill shoulder of the platform often means the land slide passes over the top of the pipeline rather than impacting it directly.

In areas of potential land slide or land slip, the pipeline wall thickness may be increased to offer supplemental protection against damage. Additionally, an external armor coating (concrete or other rock jacket) will be installed to protect the pipeline.

3.2.3 Other Comments

In general, there is almost no commercial experience where a land slide has damaged the pipeline. Application of the above design and construction techniques results in a secure pipeline installation.

In 2003, the Los Pelambres concentrate line failed due to land slip. Extreme rains washed out approximately 300 m of the pipeline platform – platform failure was significant enough that the pipeline also failed. An important footnote to this pipeline break – the failed section was installed in “fill” – not natural, undisturbed earth. This increased the risk of failure during a storm event.

A key component in resisting land slides and land slips is maintenance of the pipeline platform. Routine patrols should be made to confirm the integrity. It is possible that platform erosion could occur in wet weather. Also, drainage culverts can become plugged with debris. Routine inspection (and repair as needed) of the pipeline platform is a key factor in mitigating risk of failure. Right-of-way patrols are discussed further in Section 5.

Based on commercial operating experience and the developed pipeline design, the risk of failure due to landslide is low.



3.3 Breakage Due to Water Erosion (Rainfall and Flooding)

3.3.1 Description

During rainfall events, water soaks into the ground increasing the risk of landslips and/or landslides (see Section 2.2 above). When the ground is saturated, water runs across the surface to local low spots which usually drain to an area waterway.

The selected pipeline route crosses many streams and rivers as well as dry valleys that could become flooded during rainfall events. There is a risk at each of these crossings that erosion during a rainfall event damages the pipe. The damage could be caused by undermining supports for an aerial crossing, exposing a buried crossing, or widening the waterway exposing pipe outside the waterway. The exposed pipe may fail due to pressure of the flowing water, lack of adequate support (lost support in aerial crossing), or damage from rocks and debris moving in the river.

3.3.2 Mitigation

During the detailed engineering phase of the project, a detailed survey of the pipeline route will be made to identify all waterway crossings (active and potentially active). Geo-technical data will be collected at each site including the profile of the crossing (width from bank to bank and depth) and the width of the flood plain. Additionally, soil conditions will be evaluated at each crossing.

A hydrological survey of the region will be completed to supplement the geo-technical survey. This survey assesses the likely rainfall for a given storm event and the amount of water that could drain into each waterway crossing the pipeline corridor. This study will also determine the size of storm to be considered for design (i.e., a 1 in 100 year return period, 1 in 500, or other).

The collected hydrological and geo-technical data will be utilized to design pipeline crossings at each water way. For buried crossings and aerial spans, the potential scour depth is calculated, a safety factor added, and a minimum safe construction depth developed. This ensures the crossing can withstand the “design” storm – and has a safety factor if the storm happens to be larger.

Other design features that will be applied at river crossings to “armor” the pipeline against damage at this point include:

- The calculated minimum burial depth (buried crossings) is maintained through the entire waterway flood plain to allow for shifting of the river path within the plain.
- Buried crossings will be concrete-coated to prevent mechanical damage to the pipe if the waterway bed is shifting.



- Extra pipe wall thickness will be added at crossings – the extra thickness will be maintained through the entire waterway flood plain.
- Erosion control will be constructed for aerial span supports and at banks near the crossing to add localized protection.

3.3.3 Other Comments

Commercial experience suggests that the above design methods provide adequate protection at waterway crossings. Regular inspection of these crossings should be made after significant storm events (i.e., ROW patrols – see Section 4) to identify any repairs and/or protection needs.

The proposed slurry pipeline is a robust structural member – it will be a 22-inch diameter, high-strength steel pipe that is likely more than 0.5-inches thick at each crossing. The pipe itself offers significant resistance to mechanical damage even if exposed by a storm event.

The Alumbreira slurry pipeline in Argentina experienced two 1 in 100+ return period magnitude storms within a month. The waterway through which the pipe was installed experienced significant scour – in some cases the pipeline was undercut by several meters. Although the parallel fiber optic cable was swept away in the event, the pipeline did not fail.

The Falconbridge crude oil pipeline in the Dominican Republic has operated from more than 30 years – accumulated scour over this period exposed the pipe in several areas. The Falconbridge solution (prior to PSI involvement) was to encase the pipe in concrete and rock gabions. These cracked meaning that the oil pipeline was the primary structural member holding the “dam” in place. Despite several significant storm events (including hurricanes), no pipe failures occurred.

Proper design techniques during detailed engineering and regular inspection of the crossings is a proven methodology for minimizing risk at waterway crossings.

Based on commercial operating experience from other pipelines and the site-specific conditions in Madagascar, the risk of pipeline failure due to water erosion is medium. Implementation of a proper right-of-way inspection and maintenance program – including timely repairs – would reduce the risk of failure to a low level.

3.4 **Breakage Due to Earthquake**

3.4.1 Description

There are three major events that could damage a pipeline during a seismic event:

- Significant land shift at a specific fault could shear the buried pipeline at the point of crossing the fault.
- Liquefaction of the soil containing the pipeline during an earthquake eliminates the support causing the pipeline to sink into the earth. This could overstress the pipeline to the point of failure.
- Land/rock fall could occur dropping material onto the pipeline right-of-way. This event would be similar to a land slide event discussed in Section 3.2 above. The impact (and mitigation methods) are the same and not repeated in this section.

3.4.2 Mitigation

Again, during detailed engineering a complete geo-technical survey will be completed of the pipeline right-of-way. This survey will include an assessment of seismic activity along the right-of-way and identification of fault crossings and potential liquefaction zones.

In general, a buried pipeline is not impacted by an earthquake. As the pipeline is in the earth there is no significant moment applied to the pipe as would be typical for above-ground structures. The pipe has adequate flexibility to move with the earth – except at fault crossings.

A special design will be applied at fault crossings. The pipe will cross the fault at a perpendicular angle. The trench will be specially designed (cut back trench sides and special backfill material) to permit the pipe to move. This special trench design will extend 200 to 500 m on each side of the fault depending on the expected magnitude of the movement. In the event of a significant lateral or vertical shift across the fault, the pipe will most likely pop out of the ground.

Potential liquefaction zones are typically found in areas of fill (man-made or natural fill areas such as river deltas). The soil must also be wet – this could mean a high water table or an area such as a river delta. It is anticipated that the Ambatovy pipeline will be routed around all areas of potential liquefaction. If an area can not be avoided, friction piles will likely be installed under the pipeline. This piling provides support if the soil cannot (i.e., if liquefied during an earthquake).

3.4.3 Other Comments

There are very few known incidents of any type of pipeline failing during an earthquake. PSI has no information that a slurry pipeline has ever failed during a seismic event. The above discussed designs are effective in mitigating the risk of failure.



The fault crossing design is a commercially proven methodology. It was recently applied to the 42-inch Baku-Ceyhan crude oil pipeline at a fault crossing in Turkey with a “design” displacement of 7 meters. Conditions in Madagascar are not expected to be as severe.

Based on commercial operating experience and the developed pipeline design, the risk of failure due to an earthquake is low.



4.0 LEAK DETECTION

A primary method to mitigate the impact of any pipeline leak is early detection and implementation of emergency response. The proposed Ambatovy ore slurry pipeline will be monitored by a leak detection system. This system will analyze operating data from the SCADA including flow, pressure, density, and temperature measurement at various points along the pipeline. The system description is summarized in the following sections (reproduced from PSI's feasibility study).

4.1.1 Leak Detection System

The objective of a leak detection system is to detect system leaks and predict their location as well as issue warnings to operators. The target number for the system resolution is 3% to 5% of the flow specified in the system operating envelope as presented in the operating range. Detection is expected within 2 to 10 minutes of occurrence depending on the size and the location of the leak.

The principles of leak detection are a comparison of the flowrates, pressures, and densities along the pipeline based on current flow regime in the line and position of the pipeline valves. A leak would be recognized by the departure from established norms for these parameters.

The leak detection system is based on two methods: mass balance (MB) monitoring and section characteristic parameter (SCP) monitoring. The more reliable SCP is defined as $Q^2/(dh/dL)$, with Q representing the local flow rate and (dh/dL) representing the slope of the hydraulic gradient (headloss) in the monitoring section. The MB method alone would create false alarms when the pipeline is in transient conditions.

There will be four monitoring sections separated by a pressure measurement site (pump station, valve station, pressure monitoring station, pressure monitoring station, and terminal station). For a specific section, the value of $Q^2/(dh/dL)$ should be constant when slurry of a constant rheology flows through it. The SCP trend for the monitoring section and its neighboring section should move in the same direction if there is no leak. Leaks may be indicated when the SCP values change in different directions, or the predicted hydraulic gradient lines change at the leak point in different directions (away from a straight line at the steady state). As this method monitors trends rather than instantaneous values, it has a lower potential reading fluctuation false alarm rate.

The MB method employs the flow change rate monitoring. When pump speed or slurry batch location change (e.g., during a flushing operation), the flow rate measured at the pump station and terminal changes correspondingly. However, the change rate is in a limited range. When the change rate is higher than the tolerance, a

leak signal will be sent to the SCADA. This method is trend-based and will not be affected by a flowmeter reading drift.

The on-line monitoring of data provides pipeline operating personnel instant access to information about process flow conditions. This access to information allows safer operation and better maintenance of the pipeline. If there is an indication of a leak, an inspection team will be dispatched.

4.1.2 System Configuration

The system hardware uses instrumentation installed for other control tasks and instrumentation installed specifically for the leak detection purposes. System instrumentation used by leak detection system includes the following:

- Three flow meters (pump station, valve station, and terminal station),
- Two density meters (one each installed at the pump station and terminal),
- Four pressure transmitters (one at the pump station, two at the valve station <inlet and outlet>, and one at the terminal station), and
- Two pressure transmitters at the intermediate pressure monitoring stations along the pipeline.

The pressure transmitter installed in a remote location (intermediate PMS) will be equipped with an RTU (remote terminal unit and solar or thermal power supply).

Communication between the intermediate PMS site and the pump station will be realized fiber optic cable that will serve SCADA between both ends of the pipeline. For redundancy, the radio link will be to both ends of the pipeline. Basically, the leak detection system is thought as one of the SCADA modules.

4.1.3 Expert Advisor Software

For this study, the leak detection software is based on Pipeline AdviserTM software developed by PSI. This system has been used in the Collahuasi copper concentrate slurry pipeline (240 km, Chile), the Antamina copper/zinc concentrate slurry pipeline (300 km, Peru), and the Eskay Creek tailings slurry pipeline (6.4 km, BC, Canada). This model calculates expected (as designed conditions) hydraulic gradient along the pipeline and compares it with a calculated actual (as measured conditions) hydraulic gradient along the pipeline.

The following functions will be designed into the software.

- Graphical presentation of the pipeline operating status,
- Over-pressure and slack-flow monitoring of the whole pipeline,



- Leak detection,
- Leak location,
- Automatic batch tracking, arrival time forecast and graphical presentation on screen, and
- Expert advisor to operator.

The leak detection module will be installed in the SCADA computer and will be linked to Pipeline AdviserTM. The software will read measurements from the field instruments and analyze them per the methods discussed above in combination with the pipeline's current flow regime (steady or transient) and the position of the pipeline valves (open/closed). Corrections will be made based on the hydraulic gradient from the Pipeline AdviserTM module and the leak location detection module. Results will be displayed for operators.

The leak detection software is located in the mine site and at the plant site. It will reside in the designated PCs. A Hewlett-Packard, Pentium 1 GHz, 128 MB RAM, 20 GB HDD, Ethernet port, 24XCD, and a 17" SVGA monitor will be minimum requirements.

The leak detection system can run under Windows NT or Windows 2000, (NT is recommended) and can communicate to the DCS using Modbus protocol.



5.0 PIPELINE ROUTE INSPECTION

Another key methodology for minimizing the risk of damage due to natural events is regular inspection of the pipeline right-of-way (ROW) to identify changes that may impact pipeline integrity. Pipeline route inspection is recommended on a monthly basis – a lesser frequency may be possible once the ROW has stabilized after construction. If there are known critical areas that are sensitive to damage, more frequent inspections will be required.

The pipeline route inspection can be integrated into the right-of-way (ROW) maintenance programs.

Ground or car patrol will not be practical for much of the pipeline such that a combination of ground and air review will be required. The review is intended to identify any changes in the ROW conditions that may cause damage to the pipeline. These include:

- Excessive vegetation in the ROW.
- Changes in the ground surface (ground lowering, ground cracks, etc.).
- The area of road, railway and river/stream crossings. (Ground lowering, ground cracks).
- The condition of the marker posts.
- Construction activity in/or near the ROW.
- Status of the cathodic protection system (review of the test stations is part of the ground inspection).

Each pipeline section should be foot patrolled in accordance with the following:

Area Classification	Frequency
Rural area and stable ground	Every 12 months
Unstable Ground	Every month

In areas subject to severe erosion due to rainstorms, the timing of the patrol will be after each severe event in the affected areas.

Observations are recorded and reported to the pipeline superintendent. If a leak or imminent failure is observed it should be reported immediately to the pump station shift supervisor.

VOLUME I

APPENDIX 6.1

ATTACHMENT 3

PROCESS PLANT NATURAL HAZARDS



Ambatovy Project Process Plant Natural Risk Assessment

1.0 Introduction

The major natural hazard risks associated with the Process Plant located near Toamasina are associated with the tropical climate with a potential for severe weather conditions bringing high winds, high rainfall and ocean storm surge.

Following a Tsunami incident in the Indian ocean during December 2004, the potential effects of a Tsunami reaching the Madagascar coast near Toamasina must also be considered.

This report is intended to address the risk posed by natural hazards to the Process Plant and the related infrastructure.

1.1 Project Description

The unit operations of the Process Plant is described in the process description section of the environmental assessment. The Process Plant will be located near the city of Toamasina on the east coast of Madagascar. A tailings impoundment area will be located in valleys to the west of the Toamasina plant. A water supply will be provided by pumping station and pipeline from the Ivondro River, approximately 10 km south of the plant site. The port of Toamasina will be used extensively during construction and operations for the plant's import and export requirements.

2.0 Background

2.1 Topography and Geomorphology

The site is located geologically within the Madagascan east coastal plain. This site is predominantly a flat coastal wetland area with low undulations at elevations between 6 m and 10 m above sea level. The undulations of 1 to 2m relief are parallel to the coastline and were formed by ancient dunes. The troughs between these dunes typically become swamps during the wet season. The sandy horizons near the surface are highly permeable and free draining to canals that have been constructed to drain to the Pangalene Canal and from there to the sea. The water table underlying the undeveloped land is close to the surface.

The entire site is underlain at depth (greater than 25 m to 45 m) by migmatite with thin zones of schist / greenstone. The upper surface of this bedrock horizon has weathered in situ to form dense silty gritty sand (migmatite), becoming very soft rock and silty clay layers (schist). This residual horizon is overlain by transported sediments of recent age and alluvial / marine origin.

The lower layers of the transported sediments comprise 1 m to 4 m of argillaceous sediments of an ancient marine terrace abrasion origin. This is overlain by a series of beach, lagoonal and estuarine deposits, approximately 5 m to 10 m thick comprising alternating thin lenses of coarse and fine sand, clay, organic clay (peat) and silt. The remaining sediments, from approximately 20 m up to the surface, are reworked dune sands, composed of grey, cohesionless, medium and fine sand. The upper 1 m is coloured brown from iron oxide and organic solutes.

The natural ground water level at the site varies from surface (swamp) to approximately 2 m below grade level. The fine sand horizons encountered near the surface are of uniform grain size and are mostly cohesionless. This renders them highly permeable, which allows rapid drainage of rainwater and horizontal migration of groundwater. An average of approximately 45 m of transported, loose to medium dense sand and clayey sand underlies the site.

2.2 Climate

The climate in the Toamasina area is defined as tropical and subtropical. Rainfall occurs all year but with “drier” months between September and October. The total average annual average precipitation is estimated to be 3,300 mm. A monthly rainfall of up to 1,200 mm in March has been recorded.

Temperatures can range from a high of 30 degrees C in the summer months (February) to a minimum of 16 degrees in the winter months (July). A high level of humidity is recorded particularly through the summer months (November to March). Cyclonic weather conditions can occur throughout the summer season and occur on an annual basis.

2.3 Seismicity

The whole of Madagascar is in a region of low Seismic hazard. Design studies conducted to date have assumed a UBC Seismic Zone classification of 2B for the minesite in Moramanga and the same classification has been assumed for Toamasina. More detailed assessment of the seismic design criteria for the Toamasina site is required to establish the parameters for detailed design.

A review of historical earthquake data for the last 25 years indicates that there have been very few events recorded in or close to Madagascar. The most significant earthquake recorded in Madagascar was a magnitude 5.3 event, located approximately 100 km north of the project site. Maximum accelerations experienced at the project site would be less than 0.02 g for this event. There does not appear to any potential for large magnitude earthquakes (magnitude 7+) in the region.

3.0 Natural Hazards and Consequences

3.1 General

The potential for severe cyclonic storms, earthquake or tsunamis presents some risk to damage of structures in the Process Plant. The plant will normally operate 24 hours per day, seven days per week so economic losses will be incurred if natural hazard events interrupt operations because of evacuation of personnel, equipment damages or interruptions of raw materials supplies. Through engineering design and well planned emergency response procedures there is no reason that natural hazard events would result in injury to personnel, loss of life or transference of dangerous materials to the environment.

Drainage and containment facilities will be designed for normally expected severe conditions but these facilities could be overloaded during extreme events. Under some flooding situations, for instance, non-hazardous materials could be transported outside the plant or port facility boundaries.

3.2 Seismic Impact

Although the risks posed by seismic activity are considered to be very low, an unusual seismic event could result in damage to buildings, movement of equipment resulting in elevated stress on structural and piping components. The vibrations caused by a significant earthquake could lead to automatic shutdown of certain equipment items protected for vibration such as steam turbines. A general plant shutdown and electrical power loss could be expected as a result of a significant earthquake. In the extreme, earthquakes of magnitude greater than the design maximum regional magnitude could cause overturning of structures or ruptures in containment facilities such as tanks.

3.3 Hydrological Impact

Heavy rains accompanying tropical cyclone storms present some risk of local flooding and road and soil erosion. Cyclone storms also present the possibility of flooding from the sea in low lying areas due to result of storm surge.

3.4 Wind Impact

High speed winds are created by tropical cyclone storms. Permanent structures are designed to withstand high winds. During construction, however, special care is required to ensure camp facilities, temporary field buildings and partially erected plant equipment will not be damaged. Wind borne debris can be a major cause of personal injury and even fatalities during a severe storm.

3.5 Geotechnical Impact

The Process Plant will be constructed on level ground. There is therefore very little risk to these facilities from landslide or other geotechnical considerations due to careful foundation design for the bearing strength of the soils.

3.6 Tsunami

W. F. Baird & Associates Coastal Engineers were retained to assess the potential of tsunami hazard for the process plant and shoreline facilities.

Given the historical data and geological evidence, it is probable that future events of significant intensity will originate in subduction zones at considerable distances from Madagascar. Tsunami waves disperse with distance thus there will be a limit to the size of tsunami that will impact the eastern shorelines of Madagascar. The December 26, 2004 tsunami appears to represent an event with low probability of occurrence (a return period well over 100 years), and this tsunami originated in the north end of the subduction zone. It is possible that the south end of the zone may release and cause a significant tsunami during the life of the proposed project. Such an event, if at the same magnitude as the 2004 tsunami may cause run up in the order of 3 to 4 meters and is unlikely to cause inundation of the process plant which is located approximately two kilometers from the shore and at an elevation 6 meters above sea level.

The proposed shoreline facilities, consisting of the ship berth/jetty and products receiving station may be subject to tsunami inundation. The roads and railways connecting the shoreline facilities to the Process Plant could also be subject to inundation in low lying areas.

4.0 Risk Mitigation Through Design:

4.1 General

The risks to plant and port facilities and potential effects on the public and environment due to the identified potential natural hazards will be mitigated by a combination of engineering design to withstand the effects of the hazards and implementation of appropriate emergency response protocols. Seismic events are expected to provide no advance warning. Cyclone storms and tsunamis, on the other hand, are expected to be known with 24 hours or more advance notice which is sufficient time for implementation of shutdown and evacuation procedures at the Plant site.

4.2 Seismic Risk Mitigation

The foundations and structural members of all buildings, tanks and equipment of the Process Plant and Port will be designed for the maximum regional magnitude earthquake.

At the current stage of engineering design the facilities are assumed to require design for UBC Seismic zone 2B, which has been identified as typical for the island of Madagascar.

As detailed design progresses, further evaluation of the potential magnitude of earthquakes in the local area will be conducted and the seismic design parameters will be established. It is expected that these parameters will result in design of foundations and equipment that would withstand any earthquake that could be inferred for the area considering all available historical information. The risk of catastrophic failure of any structure is therefore very small.

Equipment vibration could result in general plant shutdown due to shutdown of electrical generators or other key equipment. Minor leaks could also be caused on flanged piping connections due to stretched bolts or strain that had not been anticipated in the plant design.

Generally, all areas of the plant will be designed to be in a safe condition on emergency shutdown due to lack of power. In the event of an earthquake, operating procedures will require immediate visual inspection of equipment and piping. In the event of leaks, the affected equipment will be shut down and isolated to stop any leaks and any necessary repairs will be affected.

Any leakage of chemicals and process solutions to the Process Plant is therefore expected to be minor in the event of an earthquake of magnitude within the expectations of the history of the area. The petroleum products storage area and the liquid chemicals and process solution handling areas in the plant site will be bermed and have appropriate equipment for recovery of spills within the bermed areas. Seismic activity to the maximum credible earthquake in the area is therefore not expected to present significant risk for the public or the environment.

An earthquake of higher intensity than the design parameters could have more serious consequences, particularly if more than one large liquid storage tank were to rupture. The plant design standard will provide storage capacity for the contents of the largest vessel in each bermed area in the case of catastrophic rupture.

The plant will not store quantities of hazardous gases such as hydrogen sulphide. A leak in equipment or piping which handles hydrogen sulphide will be detected automatically and the source of hydrogen sulphide will be isolated immediately and equipment will be vented to flare. The potential for hydrogen sulphide escape to the surroundings is therefore limited to the in-process volume of hydrogen sulphide in process equipment and piping. Although there is potential for hazard and even fatality to plant personnel in the event of a hydrogen sulphide leak the limited quantity inventoried in process equipment and piping minimizes any hazard to the public. Personnel working in areas where hydrogen sulphide is processed will be trained in emergency response and required to carry personal alarm monitors and have readily available breathing apparatus to permit their escape in the event of hydrogen sulphide fugitive emissions.

4.3 Hydrological Risk Mitigation

The design of drainage and treatment facilities at the plant site will minimize the effect of severe rainfall on the plant, the public and the environment. It is also anticipated that for the most severe potential storm events, such as a cyclone storm, plant and port operations will be suspended and all personnel with the exception of management and security personnel will be evacuated from the facilities.

In the event of cyclones reported to be approaching the Toamasina area, it is anticipated that all seagoing vessels will leave port to outside the storm area. It is also anticipated that all railway rolling stock will be moved to elevations higher than the anticipated storm surge associated with the cyclone. Port facilities, however could be inundated with storm surge associated with direct onslaught of a cyclone to the Toamasina area. There is potential for damage to port equipment and road and rail facilities by storm surge that could result in prolonged interruption of operations following a cyclone due to disruption of raw materials deliveries to the plant site. Damage to the Ivondro river pumping station from storm surge is also a possibility.

The Process Plant site located at 6 m above sea level is anticipated to be above the level of storm surge that could be associated with all but the most severe cyclone storms. The plant site design does not anticipate ocean generated storm surge at the plant site.

The Process Plant site drainage is designed with segregated bermed areas to prevent contamination of the waterways to which storm water is drained. All areas in the plant that process chemicals and solutions will be provided with concrete berms and systems of sumps and pipes to enable spills and stormwater collected in these areas to be processed. Sumps from these areas will be pumped directly to appropriate tanks in the process plant or to emergency ponds for eventual treatment in the tailings neutralization facility and settlement of neutralized solids in the tailings management facility. The rail unloading facilities and storage area for sulphur, coal and limestone storage area will also be bermed and supplied with a storm water settling pond where runoff can be collected and solids settled before the decant water is diverted to drainage to the Pangalene Canal. These facilities will prevent any contamination to the environment from storm waters during the normal course of operation with typical rain that can be anticipated on a year to year basis.

Areas surrounding administration buildings and shops, parking areas, roadways and areas without process equipment will be considered clean areas. A policy to keep these areas clean of any products spilled from mobile transport will be followed and therefore these areas will be drained directly to the system of open storm ditches and canals that drain the site to the Pangalene canal. The system of unrestrained drainage will be designed for the rains that can be expected for severe cyclone storms. The drainage design will have the capacity for maximum storm events and prevent risk of danger to the public from the volume storm water that must be drained from the plant site during a severe cyclone storm.

It is possible that the berms designed to contain contamination in process areas could be exceeded during a severe cyclone. Power outage is likely during the most severe storms so the sump systems installed in these areas could be inoperable. The potential for significant contamination of the storm water drainage system due to overflow of the berms isolating process plant areas will be mitigated by general shutdown of all of the process plant and cleanup of bermed areas prior to the onset of the storm. The combination of wind and excessive rain during a cyclone storm could result in transport of material from the sulphur, coal and limestone stockpile pads to the general drainage ditches and canal system. These materials are chemically stable and relatively innocuous if transported to the environment during the rare instance of a direct onslaught of a cyclone. During periods of heavy rains associated with cyclones centred more than 100 km away or typical 1 in 10 year storms there should be no risk of environmental contamination from plant process streams or stockpiled supplies.

4.4 Wind Risk Mitigation

All facilities constructed for the project in the coastal area will be designed to withstand sustained winds of up to 300 km/h consistent with the strongest historical cyclones. Catastrophic failure of structures, vessels or tanks due to wind is therefore not anticipated. As the plant will be shut down and vessels will be designed for severe storm wind loading, the project is not anticipated to provide risk to the public or the environment due to wind damage associated with such storms.

Wind damage to mobile equipment, windows, electrical wiring, thermal insulation and other at the port or the plant site is conceivable in the event of a severe cyclone. In addition, stockpile pads of coal, sulphur and limestone could be disrupted at the highest wind velocities during a cyclone. A plant shutdown of up to several weeks duration could be necessary for cleanup and damage repair following a direct hit on the area of a severe cyclone. A principal requirement during construction and for ongoing plant operating procedures will be maintenance of good housekeeping to prevent accumulation of items that cannot be safely stowed in the limited warning period available before the onset of a severe tropical storm or cyclone. The design of camp facilities and other temporary structures required during the construction period will take the consequences of severe winds into account. Safe refuge will be made available to accommodate personnel that may need to be evacuated.

4.5 Geotechnical Risk Mitigation

A thorough geotechnical evaluation of soil conditions is being undertaken at the plant site and port areas to ensure that foundations are adequate for the potential storm and seismic events.

4.6 Tsunami Risk Mitigation

Rail and road facilities in low lying areas and the Ivondro River pumping station could also be at risk from a tsunami event.

Although the potential for tsunami events will receive more detailed study it is not anticipated that any special design criteria for tsunami events will be required at the Process Plant site which is 6 m above sea level.

5.0 Risk Assessment and Consequence Analysis

Using the relative ranking scheme presented in Table 1, natural risks have been placed in a matrix of the likelihood of occurrence and potential consequences of each event. The risk matrix, presented in Table 2, rates the relative importance of each type of risk identified for the process plant.

Table 1 Description of Risk Criteria

Ranking Categories	Likelihood of Occurrence (Probability)		Magnitude of Consequences		Overall Risk
extremely low	1	negligible chance of occurrence, <1:10,000 yr "doubt it will ever happen"	1	no fatalities possible, minor to no damage beyond owners property	1-4
low	2	not likely to occur, 1:1,000 to 1:10,000 yr "highly unlikely to happen"	2	no fatalities anticipated, minor damages beyond owners property	5-8
moderate	3	moderate frequency of occurrence 1:100 to 1:1,00 yr "it could happen"	3	no fatalities anticipated, moderate property damages	9-14
high	4	frequent occurrences, 1:10 to 1:100 yr "it has happened, or it probably will happen"	4	some fatalities possible, large property damages	15-19
extremely high	5	very frequent occurrences, >1:10 yr "happens all the time"	5	large number of fatalities possible, extreme property damages	20-25

Note:

Ranking Category "Extremely Low" signifies negligible occurrence potential.

Details above adapted from Pelletier and Dushnisky (1993) and Davies (1998).

Table 2 Plan Site Risk Summary Matrix

Natural Hazard Source	Failure Mode (Hazard Outcome)	Consequence	Risk Mitigation through Design	Likelihood of Occurrence Ranking	Consequence Ranking	Overall Risk Rating
	1.1 Earthquake causes plant shutdown due to power failure	a) Need to shut down pipeline	Pipeline is designed for shutdown for several days duration	3	1	3
		b) Stoppage of plant units	Plant units will be designed to shut down in safe mode	3	1	3
		c) Flaring of H2S on depressurization	H2S venting from equipment will be burned to SO2	3	1	3
1.0 Seismic	1.2 Earthquake causes damage to structures	a) Building and support structures are toppled	Plant structures will be designed for maximum regional earthquake	1	4	4
		b) Leaks develop at piping joints	Earthquake loads will be considered in piping design. Connections to rigid equipment such as tanks and pumps will be in bermed areas. Inspect and isolate leaks following event	2	2	4
		c) Damage to roads or railroads cause production delay	Repairs will be effected if damage occurs, no road or railroad spills anticipated due to seismic	2	1	2
	1.3 Earthquake causes rupture of tanks	a) Rupture of large process tank such as sulphuric acid tank	Earthquake loads will be considered in tank and vessel designs. Tanks will be contained in bermed areas with berms sized for 110% of largest single vessel in area	1	4	4
	2.1 Flooding due to storm rains causes overload of bermed containment areas	a) Aggressive chemicals transferred to environment via storm drainage	Design containment berms surrounding process equipment to hold rainfall normally expected for typical annual storm events. Advanced weather reporting and emergency response plan to shut down operations in advance of severe cyclonic storms	3	2	6

Table 2 Plan Site Risk Summary Matrix (continued)

Natural Hazard Source	Failure Mode (Hazard Outcome)	Consequence	Risk Mitigation through Design	Likelihood of Occurrence Ranking	Consequence Ranking	Overall Risk Rating
		b) Stockpiled limestone, coal or sulphur overflow containment and transport to environment via storm drainage	Design containment pond for stockpile pads to hold rainfall normally expected for 1 in 10 year storm event. Stockpiled materials have relatively innocuous effect if transported to environment via storm drainage.	3	1	3
2.0 Hydrologic		c) Erosion and scouring of general plant drainage system	Design drainage ditches for cyclonic event with concrete and riprap sides and bottom	1	3	3
	2.2 Flooding due to storm surge associated with cyclonic storms	a) Aggressive chemicals transferred to environment via storm drainage	Plant elevation at 6 meters, above expected storm surge.	1	2	2
		b) Stockpiled limestone, coal or sulphur overflow containment and transport to environment via storm drainage	Plant elevation at 6 meters, above expected storm surge. Stockpiled materials have relatively innocuous effect if transported to environment via storm drainage system	1	1	1
		c) Damage to port or shipping vessels	Advance weather reporting and remove vessels from port in event of incoming cyclonic storm	2	5	10
		d) Damage to roads or railroads	Advance weather reporting and remove mobile vehicles and railway rolling stock to higher elevations in event of incoming cyclonic storm	2	3	6
		e) Damage to Ivondro river pumping station	Design pumping station to withstand high water levels	2	2	4
	3.1 Storm winds cause plant shutdown due to power failure	a) Need to shut down pipeline	Pipeline is designed for shutdown for several days duration	3	1	3
		b) Stoppage of plant units	Plant units will be designed to shut down in safe mode	3	1	3

Table 2 Plan Site Risk Summary Matrix (continued)

Natural Hazard Source	Failure Mode (Hazard Outcome)	Consequence	Risk Mitigation through Design	Likelihood of Occurrence Ranking	Consequence Ranking	Overall Risk Rating
		c) Flaring of H2S on depressurization	H2S venting from equipment will be burned to SO2	3	1	3
	3.2 Storm winds cause damage to structures	a) Building and support structures are toppled	Plant structures will be designed for wind loads of the strongest historical cyclones	1	4	4
3.0 Wind		b) Leaks develop at piping joints	Wind loads will be considered in piping design. Connections to rigid equipment such as tanks and pumps will be in bermed areas. Inspect and isolate leaks following event	2	2	4
	3.3 Storm winds cause rupture of tanks	a) Rupture of large process tank such as sulphuric acid tank	Wind loads will be considered in tank and vessel designs. Tanks will be contained in bermed areas with berms sized for 110% of largest single vessel in area	1	4	4
	3.4 Storm winds cause transport of stockpiled materials	a) Stockpiled limestone, coal or sulphur blown beyond confines of stockpile area	Storm winds normally associated with high rainfall rendering materials less mobile. Stockpiled materials have relatively innocuous effect if transported to environment	4	2	8
	3.5 Storm winds damage temporary structures and scatter debris	a) Construction or operating materials and damaged building components rendered airborne and hazardous by storm winds.	Minimize construction of facilities not designed for maximum winds, maintain good housekeeping, General cleanup and stowage of materials prior to onset of cyclonic storms. Provide secure refuge for personnel in event of cyclonic storm.	3	4	12
4.0 Geotechnical	4.1 Geotechnical damage by earthquake or flooding	a) Soils consolidation compromised by seismic event	Design foundations appropriate for geotechnical conditions and maximum regional earthquake	1	3	3
		b) Soils washed out by severe flooding event (rain or storm surge)	Design foundations and site drainage ditches appropriate for geotechnical conditions and maximum expected flooding event	2	2	4

Table 2 Plan Site Risk Summary Matrix (continued)

Natural Hazard Source	Failure Mode (Hazard Outcome)	Consequence	Risk Mitigation through Design	Likelihood of Occurrence Ranking	Consequence Ranking	Overall Risk Rating
	5.1 Site flooding caused by Tsunami event	a) Aggressive chemicals transferred to environment via storm drainage	Plant elevation at 6 meters, above expected effect of tsunami originating in East Indian Ocean.	1	2	2
5.0 Tsunami		b) Stockpiled limestone, coal or sulphur overflow containment and transport to environment via storm drainage	Plant elevation at 6 meters, above expected tsunami effect. Stockpiled materials have relatively innocuous effect if transported to environment via storm drainage system	1	1	1
		c) Damage to port or shipping vessels	Advance tsunami reporting and remove vessels from port in event of incoming cyclonic storm	1	5	5
		d) Damage to roads or railroads	Advance tsunami reporting and remove mobile vehicles and railway rolling stock to higher elevations in event of incoming cyclonic storm	1	3	3
		e) Damage to Ivondro river pumping station	Design pumping station to withstand high water levels	1	2	2

6.0 Risk Management Strategy Summary

The Process Plant and port facilities will be designed and operated in accordance with principles that will target zero risk for fatalities or personal injury to employees or the public as a result of predictable natural hazards including earthquake, tropical cyclone storms and tsunami events. The project emergency response plans will be designed to secure buildings and equipment and remove personnel from harms way on receipt of advance warning of severe tropical storms or tsunamis. Emergency response programs will be coordinated with the local communities to ensure that the public is not adversely affected by the project. The program will also ensure that the ability of the community to recover from such events is enhanced by the presence of resources available to the project.

Major structures and equipment will be designed using standard engineering practice to resist the forces anticipated from earthquakes, tropical storms and tsunamis. Such events are anticipated to cause some disruption to operations and damage to facilities depending on the severity of the event. If, during instances of severe winds or flooding, transfer of some raw materials and water born contaminants to the environment occur, emergency response procedures, monitoring and treatment processes will be in place to manage the issues.

7.0 References

- Pelletier, C.A. and K. Dushnisky. 1993. Qualitative Environmental Risk Assessment Applied to the Proposed Windy Craggy Project. Paper, Proceedings of the Seventeenth Annual British Columbia Mine Reclamation Symposium, Port Hardy, British Columbia. Sponsored by the Mining Association of British Columbia, MoELP, MoELP and the Technical and Research Committee on Reclamation. 1993
- Davies, M. P. 1998. CIM Bulletin. A Practical Risk Assessment Technique for the Mining Industry. Vol. 90, No. 1009: p. 49 – 52.

VOLUME I

APPENDIX 6.1

ATTACHMENT 4

TAILINGS FACILITY NATURAL HAZARDS

**DYNATEC CORPORATION
AMBATOVY PROJECT**

**REPORT ON NATURAL HAZARDS AND
RISK ASSESSMENT FOR THE
TAILINGS FACILITY
(REF. NO. NB301-00116/4-1)**

Rev. No.	Revision	Date	Approved
0	Issued to Client in Final	August 18, 2005	KDE
1	Re-issued to Client in Final	November 10, 2005	<i>WMB</i>

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AMBATOVY PROJECT

REPORT ON NATURAL HAZARDS AND
RISK ASSESSMENT FOR THE
TAILINGS FACILITY
(REF. NO. NB301-00116/4-1)

EXECUTIVE SUMMARY

This report outlines the potential natural hazards, potential consequences of failure and assessment of risk to resources downstream of the tailings facility. Resources downstream of the tailings facility that could be affected by potential natural hazards include human settlements, potable water and agricultural land.

The preferred tailings disposal site covers an area of approximately 9 km² and is located approximately 2 km west of the National Highway RN-2 (between Toamasina and Antananarivo) and approximately 8 km southwest of Toamasina, (Tamatave) in an area that has been deforested with few natural trees remaining.

A natural hazard is defined as a naturally occurring event that could lead to potential failure that would impact downslope or downstream resources. The natural hazards identified for the Ambatovy Project are summarized as follows:

1. Seismic Hazard - the potential damage occurring from an earthquake.
2. Hydrological Hazard - the damage occurring from a large precipitation event or cyclone.
3. Geotechnical Hazard - unforeseen geotechnical conditions could occur as an isolated event or could occur in concert with a seismic or hydrological event.

The design basis and criteria used to mitigate the natural risks defined above for the tailings facility are based on International Standards for the design of dams to minimize risk to within recognized acceptable levels for downslope or downstream resources. In particular, all aspects of the feasibility design of the tailings facility have been completed in compliance with the following three documents:

- Canadian Dam Association (CDA) Dam Safety Guidelines (CDA 1999)
- International Commission on Large Dams (ICOLD) - Tailings Dams and Seismicity - Review and Recommendations (ICOLD 1995)
- The Mining Association of Canada (MAC) Guide to the Management of Tailings Facilities (MAC 1998)

Risk is defined as the product of the probability of an event occurring multiplied by the magnitude of the consequences. On this basis, an assessment was completed to estimate the overall risk of the various hazards associated with the tailings facility. Given that the risk of natural hazards leading to dire consequences downstream of the tailings facility is considered during the design process, the risk of such an event occurring is generally very low or within normally accepted levels.

The risk assessment completed for the tailings facility shows that for most of the identified failure modes and consequences the overall risk falls in the Low and Extremely Low categories. Failure and subsequent consequences from a seismic event have the lowest overall risk rating, largely due to the fact that Madagascar is in a low seismic area. Potential failure and subsequent consequences due to a geotechnical issue have an overall risk mostly rated in the Low to Extremely Low categories, based on the assumption that detailed geotechnical investigations will be completed to adequately characterize conditions for a suitable detailed design to be implemented to the maximum degree possible.

For the hydrologic hazard source, for most of the failure mode and resulting consequences, the overall risk falls in the Low category with one result in the Moderate category and a few in the Very Low category. In general, the likelihood of a hydrologic event leading to a failure is considered higher than a geotechnical or seismic trigger event. This is due to the fact that the tailings facility is located within an area prone to extreme cyclones. The highest overall risk rating estimated is for heavy rains causing maximum flows through the water pond overflow spillways (Moderate category). Potential for overtopping and/or breaching of the water pond embankment due to heavy rainfalls has a risk rating in the upper range of the Low category. Therefore, further investigation of these types of risk scenarios has been completed in the form of modelling the identified failure processes to estimate the resultant consequences so that the magnitude can be quantified.

An inundation analyses was completed for one baseline case (pre-development) and three different event cases for the operational tailings facility. The three operational cases were as follows:

- Case 1 - Occurrence of Probable Maximum Precipitation causing spillways to flow full
- Case 2 - Occurrence of event larger than Probable Maximum Precipitation leading to breach of Water Basin embankment over a three hour period
- Case 3 - Occurrence of event larger than Probable Maximum Precipitation leading to breach of Water Basin embankment over a one hour period

Based on the analyses, it is evident that there is not a significant difference in the downstream flooding levels between the Pre-development Case and Case 1 (full spillway flows), however it is evident that there will be a significant impact to the downstream portion of TA-10 in the event of an embankment breach. In addition to the TA-10 valley, there will also be additional impacts to the east and south along the Sangalaotra River.

In order to address the potential consequences from flood levels predicted from the inundation model, a risk management strategy is proposed to minimize consequences in the case of overflow spillway discharge or embankment breach. The most significant consequence that needs to be prevented is loss of life. It is proposed that this be addressed by putting in place an Emergency Response Plan that would include an evacuation plan to remove all potentially affected downstream residents in response to a triggering event. Alternatively, consideration could be given to relocating residents within the valley to higher elevations above the projected flood levels based on the relative impact of the change in flood levels from the baseline case.

DYNATEC CORPORATION
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REPORT ON NATURAL HAZARDS AND
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APPENDICES

Appendix A	Inundation Analysis
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DYNATEC CORPORATION
AMBATOVY PROJECT

REPORT ON NATURAL HAZARDS AND
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(REF. NO. NB301-00116/4-1)

SECTION 1.0 - SCOPE

This report outlines the potential natural hazards, potential consequences of failure and assessment of risk to resources downstream of the tailings facility. The project site location is shown on Figure 1.1. The mine site area is shown on Figure 1.2 while the tailings facility and plant site areas are presented on Figure 1.3. The potential natural hazards are from seismic, hydrological or geotechnical sources. Resources downstream of the tailings facility include human settlements, potable water and agricultural land. The report summarizes the structures associated with the facilities and the mitigation of risk employed through design by employing conservative assumptions and adhering to general international accepted standards for design. All potential failure modes are identified and the potential consequences from such failures are reviewed, both qualitatively and quantitatively.

It should be noted that only natural hazard risks have been addressed in this report. Risks associated with improper operations is documented as one of the more significant areas that should be addressed for tailings facilities. Mitigation and management of such operating risk is usually handled through development and implementation of a proper Operations, Maintenance and Surveillance (OMS) Manual for a tailings facility. This will be addressed separately at a future phase of the project.

SECTION 2.0 - SETTING FOR PREFERRED OPTION

2.1 GENERAL

Several sites were studied to determine the preferred option for tailings storage. The preferred option for tailings storage was found to be in the Tamatave Area. The preferred tailings disposal site is located approximately 2 km west of the National Highway RN-2 (between Toamasina and Antananarivo) and approximately 8 km southwest of Toamasina, as shown on Figure 1.1. The area has been deforested and few natural trees remain in the area.

The tailings disposal site covers an area of approximately 9 km², extending towards the west from the RN-2 road. An east-west trending access road (spine road) runs through the central portion of the site. This road was mainly built to provide access to the dolerite dyke quarries, situated at the higher elevated western portion of the site. The dolerite quarries provided material for road construction. Most of these quarries are not currently being utilized (one quarry operation was active). A powerline runs parallel to the access road. Figures 2.1 to 2.3 present plan views of the tailings facility from Phase 1 to Phase 3 and represent tailings storage for the entire 27 year mine life.

2.2 EXISTING LAND USE

The two main land uses by the community include rice cultivation and wattle tree plantations on a small scale. The rice paddies are situated in the low lying drainage features. The wattle tree plantations are mainly situated on hill crests in the eastern portion of the site. The poles produced from the wattle trees are primarily used for the construction of houses. Natural vegetation, including bamboo and banana leaves, are also used for the building of houses and roofing.

One dolerite quarry, operating as a one-man business on a very small scale, exists within the boundaries of the current investigation area and is situated in the western portion of the site.

2.3 TOPOGRAPHY AND GEOLOGY

The site is characterized by three west to east trending naturally formed valleys, as shown on Figures 2.1 to 2.3. The drainages within these valleys are utilized for rice paddies. Drainage flows in an easterly direction towards the north to south trending Sangalaoatra River which flows south into the Ivandro River. The highest elevation is in the western portion of the site at approximately El. 90 m, while the lowest elevation is in the far eastern portion of the site at El. 4 m. The valleys slope down at a natural gradient of less than 6 degrees (10%).

Geological maps of the area show that the major rock types are gneiss, biotite gneiss, migmatite and mica schist of the Ambodiriana Series of the Vohibory System. These rocks have been intruded by numerous north to south trending dolerite dykes that intersect the area, also northwest to southeast trending amphibolite and schist zones. An axial syncline occurs in the eastern portion of the site. Surficial deposits consisting of alluvium (including clay, sand and gravel) occur within and along drainage features and rivers.

2.4 CLIMATE

The climate in the Tamatave area is defined as tropical and subtropical. Rainfall occurs all year but with “drier” months between September and October. The total annual average precipitation is estimated to be 3,300 mm. Monthly average rainfalls vary between 116 to 128 mm (October and September) to between 425 to 479 mm (February and March). A monthly rainfall of up to 1,200 mm in March has been recorded.

Temperatures can range from 30 °C in the summer months (February) to a minimum of 16 °C in the winter months (July). A high level of humidity is recorded particularly through the summer months (November to March). Evaporation, as expected in these conditions, is relatively low and varies between 60 mm (June) to 85 mm (January). The annual average lake evaporation is estimated to range from 700 to 1,000 mm.

Cyclones occur annually throughout the summer season. In order to estimate Probable Maximum Precipitation for the Tamatave Area recorded storm data from Reunion have been adopted until available data for Tamatave can be assessed. Recorded maxima for Tamatave are 1,300 mm for 12 hours and 1,900 mm for 24 hours. These values represent some of the highest recorded rainfalls in the world.

2.5 SEISMICITY

The whole of Madagascar is in a region of low seismic hazard. A review of historical earthquake data for the last 25 years indicates that there have been very few events recorded in or close to Madagascar. The most significant earthquake recorded in Madagascar was a Magnitude 5.3 event, located approximately 100 km north of the project site. Maximum accelerations experienced at the project site would be less than 0.02g for this event. There does not appear to be any potential for large magnitude earthquakes (Magnitude 7+) in the region.

Seismicity in southeastern Africa is generally associated with the East African Rift Zone. Normal faulting appears to characterize the scattered seismicity throughout the region between Madagascar and the eastern arm of the East African Rift Zone. The largest earthquake sequence to have struck eastern Africa within the past 75 years occurred in May and June of 1985 off the coast of the Tanzania-Mozambique border, approximately 350 km northwest of Madagascar. The largest earthquake recorded in this sequence was a Magnitude 6.4 event. However, the potential seismic hazard from future events in this region is negligible as they are located over 1,000 km from the project site (Campbell, 1997).

For future design studies, it is recommended that a more detailed assessment of the regional geology and seismicity be carried out to provide a more definitive Maximum Credible Earthquake for the project site.

SECTION 3.0 - NATURAL HAZARDS AND CONSEQUENCES

3.1 GENERAL

The Canadian Dam Association (CDA) dam hazard classification selection criteria were used to determine the overall hazard potential (consequence rating) for the tailings facility based on the effects of a dam failure. A dam is generally classified in accordance with the severity of hazard resulting from failure of the dam or its associated structures and the perceived risk of occurrence. This hazard classification forms the basis for the design requirements and ongoing surveillance activities. Dam classification considers the potential incremental consequences of failure, which includes potential loss of life, economic damages, social and environmental impacts. Due to downstream inhabitants and the proximity to Tamatave, failure of the tailings facility could lead to:

- Significant fatalities
- Significant impacts in terms of socio-economic, environmental and financial factors such as loss of potable water and arable land and the cost to rebuild or relocate the local population

Therefore, the tailings facility is classified in the Very High Consequence Category.

3.2 NATURAL HAZARDS

A natural hazard is defined as a naturally occurring event that could lead to potential failure that would impact downslope or downstream resources. A natural hazard and consequence inventory has been developed for the tailings facility to determine potential sources of failure and potential consequences, as discussed below and as shown on Table 3.1.

3.2.1 Seismic Hazard

The potential damage occurring from an earthquake is considered a seismic hazard. The ground motions from an earthquake could trigger the following:

- A landslide in the watersheds of the tailings or water basins which could cause overtopping or breaching of the embankments
- Liquefaction of the tailings, embankments and/or foundation which could cause overtopping or breaching of the embankments
- The creation of a tsunami due to an offshore earthquake which could travel inland and damage the embankments

3.2.2 Hydrological Hazard

A hydrological hazard is determined as the damage occurring from a large precipitation event or cyclone. The heavy rains or high winds could trigger the following:

- A landslide in the watersheds of the tailings or water basins which could cause overtopping or breaching of the embankments

- Inundation of the tailings and water basins where the overflow spillways would pass the maximum designed flows in a safe and controlled manner. This would cause flooding downstream of the tailings facility.
- Inundation of the tailings and water basins where the overflow spillways could not pass the storm flows in a safe and controlled manner. This could cause overtopping or breaching of the embankments.
- Erosion and failure of the embankments which could cause release of tailings and or process water to the environment
- The creation of a large wave from high winds that could overtop or breach the embankments

3.2.3 Geotechnical Hazard

Unforeseen geotechnical conditions could occur as an isolated event or could occur in concert with a seismic or hydrological event. Unforeseen geotechnical conditions could trigger the following:

- A landslide in the watersheds of the tailings or water basins which could cause overtopping or breaching of the embankments
- A landslide along the embankments due to poor foundation conditions, excessive seepage (piping) and oversteepening of the embankments could cause overtopping or breaching of the embankments

3.3 RISK MITIGATION THROUGH DESIGN

The design basis and criteria for the tailings facility are based on international standards for the design of dams to minimize risk to within recognized acceptable levels for downslope or downstream resources. In particular, all aspects of the feasibility design of the tailings facility have been completed in compliance with the following three documents:

- Canadian Dam Association Dam Safety Guidelines (CDA 1999)
- International Commission on Large Dams (ICOLD) - Tailings Dams and Seismicity - Review and Recommendations (ICOLD 1995)
- The Mining Association of Canada (MAC) Guide to the Management of Tailings Facilities (MAC 1998)

On tailings dams, the CDA guidelines state that "tailings dams and their appurtenant structures must be protected against the same hazards and to the same extent as embankment dams...". As noted above in Sub-section 3.1, the consequence rating for the tailings facility has been selected as "Very High". Selection of this consequence rating requires that the Maximum Credible Earthquake and Maximum Probable Flood be used for design criteria. In addition, a detailed geotechnical investigation will be required during the detailed design stage commensurate with the consequence rating.

Table 3.1 lists pertinent strategies and processes that will be employed in the design of the tailings facility to mitigate identified risks. It should be noted that only general design elements are presented in this document. More detailed descriptions, design parameters, analyses and structures, operational procedures and recommendations for further study are discussed in the Updated Feasibility Study Report (Knight Piésold Ref. No. NB301-116/3-1). General designs to mitigate the risk to downslope or downstream resources are discussed below.

3.3.1 Seismic Design

Consistent with current design philosophy for geotechnical structures such as dams, two levels of design earthquake should be considered as follows (ICOLD, 1995):

- Operating Basis Earthquake for normal operations
- Maximum Design Earthquake for extreme conditions

The Operating Basis Earthquake is typically determined using the probabilistic seismic hazard analysis to select an acceptable hazard level, based on the probability of exceedance over the design life of the facility. This is often chosen as the earthquake that has a 10 percent probability of exceedance in 50 years, corresponding to a return period of 475 years. Assuming a design life of 27 years the probability of exceedance is 5.7%. The maximum acceleration for the 1 in 475 year earthquake is approximately 0.04g. The tailings facility would be expected to function in a normal manner after the Operating Basis Earthquake.

An appropriate Maximum Design Earthquake for the tailings facility has been determined based on a hazard classification of the facility, with consideration of the Very High consequence category. Therefore, the Maximum Design Earthquake is taken as the Maximum Credible Earthquake. A conservative design earthquake of Magnitude 6.0 causing a maximum acceleration of 0.16g at the project site has been determined for the Maximum Credible Earthquake based on the review of historical seismicity (United States Geological Service, 2005 and Global Seismic Hazard Assessment Program, 1999). Limited deformation of the embankments is acceptable under seismic loading from the Maximum Design Earthquake, provided the overall stability and integrity of the facility is maintained and that there is no release of stored tailings or water (ICOLD, 1995).

The maximum accelerations of 0.04g and 0.16g for the Operating Basis Earthquake and Maximum Design Earthquake events, respectively, are for ground motions in bedrock or firm ground through which ground amplification effects are negligible. Maximum accelerations within the tailings and water basin embankments may be higher due to amplification of ground motion through the foundation soils and the tailings facility. Potential for amplification was not reviewed as part of the feasibility design but will be determined for detailed design when refined analyses are completed.

Generalized stability models to determine the seismic stability were developed based on the designed embankment cross sections. The models were analyzed using the limit

equilibrium stability modelling program SLIDE. Material parameters used for the analyses were based on the test results available. A maximum seismic coefficient of 0.16g was adopted for the pseudo static analyses based on the Maximum Design Earthquake previously discussed. Results from the pseudo static stability analysis expressed as Factor of Safety, must be greater than 1.0 to maintain stability and prevent deformation during an earthquake. All the pseudo static cases analysed met this requirement. These results indicate that under the Maximum Design Earthquake, there would be no movement or displacement of the embankments.

During the detailed design phase of the project, additional site investigations and testing of materials will be completed to confirm findings of the feasibility design. Based on the design process, the risk of failure during a seismic event will generally be extremely low due to the employment of international standards, sound research, detailed data collection and detailed analyses. In addition, the design earthquake employed is the Maximum Credible Earthquake, or the maximum earthquake that could ever happen in this region based on available seismic and tectonic information. Therefore, smaller, more frequent earthquakes will not adversely affect the tailings facility and operations could continue immediately following a smaller earthquake.

3.3.2 Hydrologic Design

Two design storms were considered for the tailings facility as follows:

- **Environmental Design Storm** - The Environmental Design Storm is defined as the maximum 24 hour event that the tailings facility should be capable of containing prior to untreated discharge being released directly to the environment through an overflow spillway (South Africa, 1998). In Africa, the accepted return period for an Environmental Design Storm for tailings facilities is a 1 in 50 year event. An Environmental Design Storm with a lower return period can be proposed if the environmental impact is shown to be acceptable. At this stage of the project, a 1 in 50 year 24-hour storm event has been selected for the Environmental Design Storm until more detailed information is available. As no site specific 24-hour storm event was available for the Tamatave area at the time of the feasibility design, a value of 500 mm for a 1 in 50 year event was used for the Environmental Design Storm. Once available meteorological data for Tamatave has been assessed, a more accurate value will be adopted for detailed design.
- **Inflow Design Flood** - The Inflow Design Flood for a facility with a Very High consequence rating is the Probable Maximum Flood. The tailings facility will need to be capable of passing the Probable Maximum Flood in a safe and controlled manner through adequately sized overflow spillways to protect the embankments from overtopping and breaching. The Probable Maximum Flood is based on the Probable Maximum Precipitation event with a duration that causes the maximum peak flow through the overflow spillway. In order to estimate the Probable Maximum Precipitation for the Tamatave area, recorded world record storm data for Reunion were reviewed

and used to adjust the world maxima. Based on this assessment, a 12-hour Probable Maximum Precipitation of 1,300 mm as well as corresponding values for shorter durations have been adopted for design of the overflow spillways.

The tailings facility has been designed to contain the Environmental Design Storm above the Normal Maximum Operating Level (NMOL). Based on a preliminary estimate for the 1 in 50 year storm (500 mm in 24 hours - to be updated once site specific data is assessed), it is estimated that 4 Mm³ of storage will be required in the water basin above the NMOL. Therefore the water basin has been designed to hold up to 7 Mm³ to the overflow spillway invert level, including the operational water storage allowance of 3 Mm³.

The tailings facility will be able to safely pass an Inflow Design Flood equivalent to the Probable Maximum Precipitation. Therefore, sufficient freeboard (wet freeboard) must be provided above the Environmental Design Storm level to pass the Probable Maximum Precipitation through a suitably sized overflow spillway. In addition, freeboard above the Inflow Design Flood maximum flood level (dry freeboard) will be provided to handle wave run-up during a cyclone. The dry freeboard required was determined to be approximately 2 m, based on a wind velocity of 200 km/hr and a fetch distance of 1 km (Mitchell, 1983).

Based on the analyses carried out from the feasibility design, the Inflow Design Flood will result in peak flows from the tailings basins to the water basins that range from 107 m³/s to 209 m³/s. Peak outflows for the water basin will range from 208 m³/s to 368 m³/s. Based on these predicted flows, spillway widths of 100 m from the tailings basin to the water basin and 200 m from the water basin to the environment will allow the flows to be passed in a safe and controlled manner with less than 1 m of wet freeboard.

The Probable Maximum Flood used in this analysis does not have a return period, as it is assumed that the rainfall from this storm is the absolute highest. Therefore, storms with return periods will be smaller than the design storm which assures that the spillways will pass storm flows in a safe and controlled manner. By selecting the Probable Maximum Flood for design of storm routing measures, the risk of overtopping the embankment during a storm event is very low.

In addition to the selection of the Probable Maximum Flood for storm routing measures design, the tailings facility has been designed to prevent the risk of massive discharge of tailings solids to the environment to the greatest extent possible. This has been achieved by routing all operational flows through the water basin and creating tailings beaches against the highest tailings embankments which places the water pond far away from the tailings embankments. The tailings basin spillway invert elevation is 4 m below the embankment elevation. Therefore, all storm flows will be naturally routed through the spillways as shown on the storm routing sections presented on Figure 4.1.

3.3.3 Geotechnical Design

Embankments will be constructed in the locations shown on Figures 2.1 through 2.3. All tailings embankments will be constructed using the centreline method, except for limited sections where the supernatant pond will be against the embankments at the spillway locations. These areas will be constructed using downstream construction.

The proposed cross sections for the embankments at the tailings and water basins are shown on Figure 4.1. The cross sections are very similar and consist of an upstream zone of select silty clay fill (Residual Gneiss) and a downstream zone of local random fill, which may consist of residual gneiss but may include coarser less weathered material.

A vertical chimney drain (sand filter zone) is located between the upstream and downstream zones. The chimney drain will collect any seepage through the upstream zone, while ensuring that internal stability is maintained by preventing the migration of particles to the downstream zone. A foundation drain system will collect seepage from embankment and foundation units. This will minimize pore pressures in the embankment and foundation. The drains will also enhance embankment stability by ensuring that the phreatic surface is maintained at low levels within the foundation and downstream embankment zone. Seepage from the drains will be collected in a lined seepage pond downstream of the ultimate toe of the embankments and pumped back to the tailings impoundment if water quality is not suitable for discharge. Detailed seepage analyses will be carried out during detailed design to determine the size of the drainage and collection structures.

Instrumentation, such as vibrating wire piezometers, slope inclinometers, monitoring wells and flow weirs, will be installed in the foundations, embankments and downstream of the embankments. Regular monitoring of the instrumentation will be completed and annual reviews will be carried out by a suitably qualified person to evaluate the performance of the tailings facility and to recommend any necessary remedial actions. Appropriate trigger levels will be set for the instrumentation.

Generalized stability models were developed based on the embankment cross sections and materials described above. The models were analyzed using the program SLIDE. Material parameters used for the analyses were based on test results available at the time the feasibility design was completed. The required Factor of Safety for the long-term static case, as recommended by the CDA, is 1.5 and all analysed cases met this criteria. The short-term period following construction of the initial embankments (when high pore pressures may exist within the embankment fill) will be evaluated as part of the detailed design for the project, when more data is available. This case will consider the undrained strength of the fill.

Additional site investigations and testing of materials will be completed to confirm findings of the feasibility design during the detailed design phase of the project. Based on the design process, the risk of failure due to a geotechnical flaw will generally be extremely low

due to the employment of international standards, sound research, detailed data collection and detailed analyses. In addition, international standards for Factor of Safety (i.e. 1.5) will be followed using conservative material parameters to ensure that the design is adequate.

SECTION 4.0 - RISK ASSESSMENT

4.1 GENERAL

Risk is defined as the product of the probability of an event occurring multiplied by the magnitude of the consequences. In order to determine if a risk is acceptable, an assessment is required to estimate the overall risk by considering the likelihood of an event occurring and the magnitude of the consequences. As it is difficult to quantify in numerical terms probability and magnitude, a relative risk ranking or rating scheme is usually employed.

As discussed in Section 3.0, the risk of natural hazards leading to a failure of the tailings facility thereby leading to dire consequences downstream is considered in the design process. Through application of internationally accepted design criteria and analyses, the risk of such an event occurring will be very low or within normally accepted levels. When assessing the likelihood of occurrence the risk mitigation through design measures need to be taken into account.

Following completion of a relative risk assessment, more thorough analysis of the highest risk events can be completed if the level of risk justifies this. This usually involves modelling the identified failure process to estimate the resultant consequences so that the magnitude can be quantified. Depending on the level of risk, measures may be taken to remove the risk or further minimize it. In some cases, minimizing the risk may be as simple as developing an Emergency Response Plan to evacuate people should a situation that could lead to failure start to develop.

The sub-sections below summarize the methodology and results of a relative risk assessment completed for the tailings facility. This includes a relative risk assessment to identify higher risk events and inundation analyses to quantify potential consequences of identified events.

4.2 RELATIVE RISK ASSESSMENT

Table 4.1 summarizes the relative ranking scheme that has been employed for conducting a relative or subjective risk assessment for the tailings facility. As shown on Table 4.1, five ranking categories have been used to rank Likelihood of Occurrence (Probability) and Magnitude of Consequences. Numerical values from 1 to 5 have been applied to the categories with the higher number representing higher likelihood of occurrence or magnitude of consequences. A general definition has been included for each of the ranking categories and levels. Five overall risk ranges have been specified based on the highest potential product of Likelihood of Occurrence multiplied by Magnitude of Consequences.

The ranking scheme on Table 4.1 has been applied to the identified failure modes and consequences summarized on Table 3.1. The results are presented on Table 4.2 and discussed below.

In terms of what is acceptable for Overall Risk Rating, the Extremely Low category is no doubt the best outcome. The Low category is considered acceptable although further work may be required to understand the risk better so that further mitigation measures can be developed. Any Overall

Risk Ratings that are in the Moderate category or higher require additional study and completion of a mitigation plan of some sort.

The results of the risk assessment shown on Table 4.2 show that for most of the identified failure modes and consequences the overall risk falls in the Low and Extremely Low categories. Failure and subsequent consequences from a seismic event have the lowest overall risk rating. This is largely due to the fact that Madagascar is in a low seismic area and that application of conservative seismic design parameters should more than address seismic concerns. Potential failure and subsequent consequences due to a geotechnical issue have an overall risk mostly rated in the Low to Extremely Low categories. This is based on the assumption that detailed geotechnical investigations will be completed to adequately characterize conditions for a suitable detailed design to be implemented. Adequate geotechnical characterization will ensure that the chance of any large scale failure and massive release of tailings and/or supernatant water will be very low while the chances of a small scale failure leading to embankment damage or a small release will be slightly higher due to the possibility of smaller geological features being missed.

For the hydrologic hazard source, for most of the failure mode and resulting consequences the overall risk falls in the Low category with one result in the Moderate category and a few in the Very Low category. In general, the likelihood of a hydrologic event leading to a failure is considered higher than a geotechnical or seismic trigger event. This is due to the fact that the tailings facility is located within an area prone to extreme cyclones and there is generally less understanding of precipitation or meteorological patterns than there will be of seismic and geotechnical conditions. The highest overall risk rating estimated is for heavy rains causing maximum flows through the water pond overflow spillways (Moderate category). Potential for overtopping and/or breaching of the water pond embankment due to heavy rainfalls has a risk rating in the upper range of the Low category. Therefore, further investigation of these types of risk scenarios has been completed and is summarized in the next sub-section.

4.3 QUANTITATIVE CONSEQUENCE ANALYSES

4.3.1 General

In order to better understand the consequences of two scenarios noted above, an inundation analyses was completed to estimate downstream areas of impact for the following hydrologic hazard sources:

- Heavy rain causing maximum designed flows to pass through water pond spillway
- Heavy rain causing inundation of tailings facility and breaching of water pond embankment

The arrangement of the tailings facility selected for the analyses, shown on Figure 4.1, is representative of a period around Year 18 to 20 in operations when runoff from both the Phase 1 and Phase 2 Tailings Basins could still be reporting to the Phase 1 and 2 Water Basin. This represents the potential worst case for hydrological routing as it represents the time when the largest area of runoff will be reporting to the Water Basin overflow spillway.

As shown on Figure 4.1 Sections 1 and 2, the tailings facility has been designed to ensure all extreme flows are routed through the Water Basin by keeping the tailings embankments 4 m higher than the overflow spillway invert level. In addition tailings will be discharged against the tailings embankments keeping water away from them as much as possible.

For modelling purposes, the computer program HEC-RAS[®] was used. A total of four cases were analysed as follows:

Pre-Development Case - Occurrence of Probable Maximum Precipitation prior to construction of tailings facility and Water Basin embankments (baseline case).

Case 1 - Occurrence of Probable Maximum Precipitation causing spillways to flow full.

Case 2 - Occurrence of event larger than Probable Maximum Precipitation leading to breach of Water Basin embankment. For this case, a period of three hours was assumed for full breach development in the Water Basin embankment.

Case 3 - Occurrence of event larger than Probable Maximum Precipitation leading to breach of Water Basin embankment. For this case, a shorter period of one hour was assumed for full breach development in the Water Basin embankment.

The final case was modelled as a worst case scenario due to the unknown duration over which full breach of the embankment would occur. A shorter period for full embankment breach, results in a higher outflow hydrograph, creating increased flooding levels to the downstream.

Further details of the HEC-RAS[®] model for cases 1, 2 and 3 and analyses methodology can be found in Appendix A. The results are discussed below.

4.3.2 Inundation Analyses Results

The results of the inundation analyses are shown on Figures 4.2 and 4.3. As shown the downstream limit of the model is the outlet of the TA-10 valley just upstream of the confluence with the Sangalaoira River which flows south. The model was not extended past this as due to lack of detailed topography. In addition extending the model further downstream would need to include routing of flows from the TA-11 valley to the north which would require a more detailed model. The estimated flooding limits at the peak flow for the four modelled cases are shown on Figure 4.2 while the respective levels along the TA-10 valley are shown on Figure 4.3. The flooding limits for Case 1 are very similar to the base Pre-development Case. In general, flooding levels for Case 1 are 1 to 2 m higher than the Pre-development Case. As shown on the figures, the water depths in the bottom of the TA-10 valley are between 4 to 5 m at the peak flow for Case 1 and as high as 10 m for Cases 2 and 3. Based on the predicted peak water level for Case 1 at the east end of the TA-10 valley, it is apparent that flood levels would be contained to the east and would

not impact RN-2. However, for Cases 2 and 3, it is likely that flood levels may be above RN-2 in this area thereby impacting other land uses to the east.

Based on the inundation analyses, the following is summarized:

- Spillway flows up to the PMP will not cause flows much higher than the Pre-development Case suggesting that the impact is limited under this comparison.
- It is evident that there will be a significant impact to the downstream portion of TA-10 in the event of an embankment breach.
- In addition to the TA-10 valley, there will also be additional impacts to the east and south along the Sangalaoatra River in the event of an embankment breach (Cases 2 and 3).
- As noted above the design of these structures will be completed to greatly minimize the chance of occurrence for a breach.

4.3.3 Risk Management Strategy

In order to address the potential consequences from flood levels predicted from the inundation model, a risk management strategy is required to minimize consequences in the case of overflow spillway discharge or worse. The most significant consequence that needs to be prevented is loss of life. It is proposed that this be addressed by putting in place an Emergency Response Plan. The Emergency Response Plan would need to include a trigger mechanism that would likely be based on high Water Basin levels in conjunction with oncoming precipitation that could lead to discharge through the spillway. Under this scenario, an evacuation plan would be implemented to remove all potentially affected downstream residents until the risk of high spillway flow has passed. Alternatively, consideration could be given to moving residents within the valley to higher elevations above the projected flood levels. The need to re-locate people would be dependant on the relative impact of the change in flood levels from the baseline case.


SECTION 5.0 - REFERENCES

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SECTION 6.0 - CERTIFICATION

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TABLE 3.1
DYNATEC CORPORATION
AMBATOVY PROJECT
REPORT ON NATURAL HAZARDS AND RISK ASSESSMENT FOR THE TAILINGS FACILITY
HAZARD AND CONSEQUENCE SUMMARY

Natural Hazard Source	Failure Mode (Hazard Outcome)	Consequence	Risk Mitigation through Design
1.0 Seismic	1.1 earthquake causing landslide in watershed	a) overtopping of tailings embankment causing release of process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway
		b) breach of tailings embankment causing release of tailings and process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway
		c) overtopping of water pond embankment causing release of process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway
		d) breach of water pond embankment causing release of process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway
	1.2 earthquake causing liquefaction of tailings embankment	a) overtopping of tailings embankment causing release of process water to the environment	Detailed, state of the art geotechnical testing of tailings, fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, design earthquake ground motions and deformations, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)
		b) breach of tailings embankment causing release of tailings and process water to the environment	Detailed, state of the art geotechnical testing of tailings, fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, design earthquake ground motions and deformations, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)
	1.3 earthquake causing liquefaction of water pond embankment	a) overtopping of water pond embankment causing release of process water to the environment	Detailed, state of the art geotechnical testing of tailings, fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, design earthquake ground motions and deformations, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)
		b) breach of water pond embankment causing release of process water to the environment	Detailed, state of the art geotechnical testing of tailings, fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, design earthquake ground motions and deformations, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)
	1.4 tsunami causing erosion of tailings embankment	a) breach of tailings embankment causing release of tailings and process water to the environment	Detailed, state of the art geotechnical testing of tailings, fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, erosion protection measures, embankment freeboard
	1.5 tsunami causing erosion of water pond embankment	b) breach of water pond embankment causing release of process water to the environment	Detailed, state of the art geotechnical testing of tailings, fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, erosion protection measures, embankment freeboard
2.0 Hydrologic	2.1 heavy rain causing landslide in watershed	a) overtopping of tailings embankment causing release of process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway
		b) breach of tailings embankment causing release of tailings and process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway
		c) overtopping of water pond embankment causing release of process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway
		d) breach of water pond embankment causing release of process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway
	2.2 heavy rain causing maximum flows through water pond spillway	a) flooding and damage to downstream resources	Conservative selection of design storm (PMP), inundation studies, storm routing design, spillway design, embankment freeboard
	2.3 heavy rain causing inundation of tailings embankment	a) overtopping of tailings embankment causing release of process water to the environment	Conservative selection of design storm (PMP), inundation studies, storm routing design, spillway design, embankment freeboard
		b) breach of tailings embankment causing release of tailings and process water to the environment	Conservative selection of design storm (PMP), inundation studies, storm routing design, spillway design, embankment freeboard
	2.4 heavy rain causing inundation of water pond embankment	a) overtopping of water pond embankment causing release of process water to the environment	Conservative selection of design storm (PMP), inundation studies, storm routing design, spillway design, embankment freeboard
		b) breach of water pond embankment causing release of process water to the environment	Conservative selection of design storm (PMP), inundation studies, storm routing design, spillway design, embankment freeboard
	2.5 high winds causing large wave at tailings embankment	a) overtopping of tailings embankment causing release of process water to the environment	Conservative selection of design wind (200 km/h), spillway design, embankment freeboard
		b) breach of tailings embankment causing release of tailings and process water to the environment	Conservative selection of design wind (200 km/h), spillway design, embankment freeboard
3.0 Geotechnical	2.7 poor geotechnical conditions causing landslide in watershed	a) overtopping of tailings embankment causing release of process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway
		b) breach of tailings embankment causing release of tailings and process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway
		c) overtopping of water pond embankment causing release of process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway
		d) breach of water pond embankment causing release of process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway
	2.8 poor, unforeseen foundation conditions causing tailings embankment failure	a) minor slump leading to temporary release of tailings and/or process water to the environment	Detailed, state of the art geotechnical testing of tailings, fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)
		b) major slump leading to loss of freeboard and breach of tailings embankment causing major release of tailings and/or process water to the environment	Detailed, state of the art geotechnical testing of tailings, fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)
	2.9 poor, unforeseen foundation conditions causing water pond embankment failure	a) minor slump leading to temporary release of tailings and/or process water to the environment	Detailed, state of the art geotechnical testing of tailings, fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)
		b) major slump leading to loss of freeboard and breach of tailings embankment causing major release of tailings and/or process water to the environment	Detailed, state of the art geotechnical testing of tailings, fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)

I:\301-00116-4\Assignment\Report\Report 1, Rev. 1\Table 3.1, Table 4.2.xls|Table 3.1
10-Nov-05

TABLE 4.1

DYNATEC CORPORATION
AMBATOVY PROJECT

REPORT ON NATURAL HAZARDS AND RISK ASSESSMENT FOR THE TAILINGS FACILITY

RELATIVE RANKING SCHEME

Ranking Categories	Likelihood of Occurrence (Probability)		Magnitude of Consequences		Overall Risk
Extremely Low	1	Negligible chance of occurrence, <1:10,000 yr "doubt it will ever happen"	1	No fatalities possible, minor to no damages beyond owners property	1 - 4
Low	2	Not likely to occur, 1:1,000 to 1:10,000 yr "highly unlikely to happen"	2	No fatalities anticipated, minor damages beyond owners property	5 - 8
Moderate	3	Moderate frequency of occurrence, 1:100 to 1:1,000 yr "it could happen"	3	No fatalities anticipated, Moderate property damages	9 - 14
High	4	Frequent occurrences, 1:10 to 1:100 yr "it has happened, or it probably will happen"	4	Some fatalities possible, Large property damages	15 - 19
Extremely High	5	Very frequent occurrences, >1:10 yr "happens all the time"	5	Large number of fatalities possible, Extreme property damages	20 - 25

I:\301-00116-4\Assignment\Report\Report 1, Rev. 1\Table 4.1 - Subjective Ranking Scheme.xls]Table 4.1

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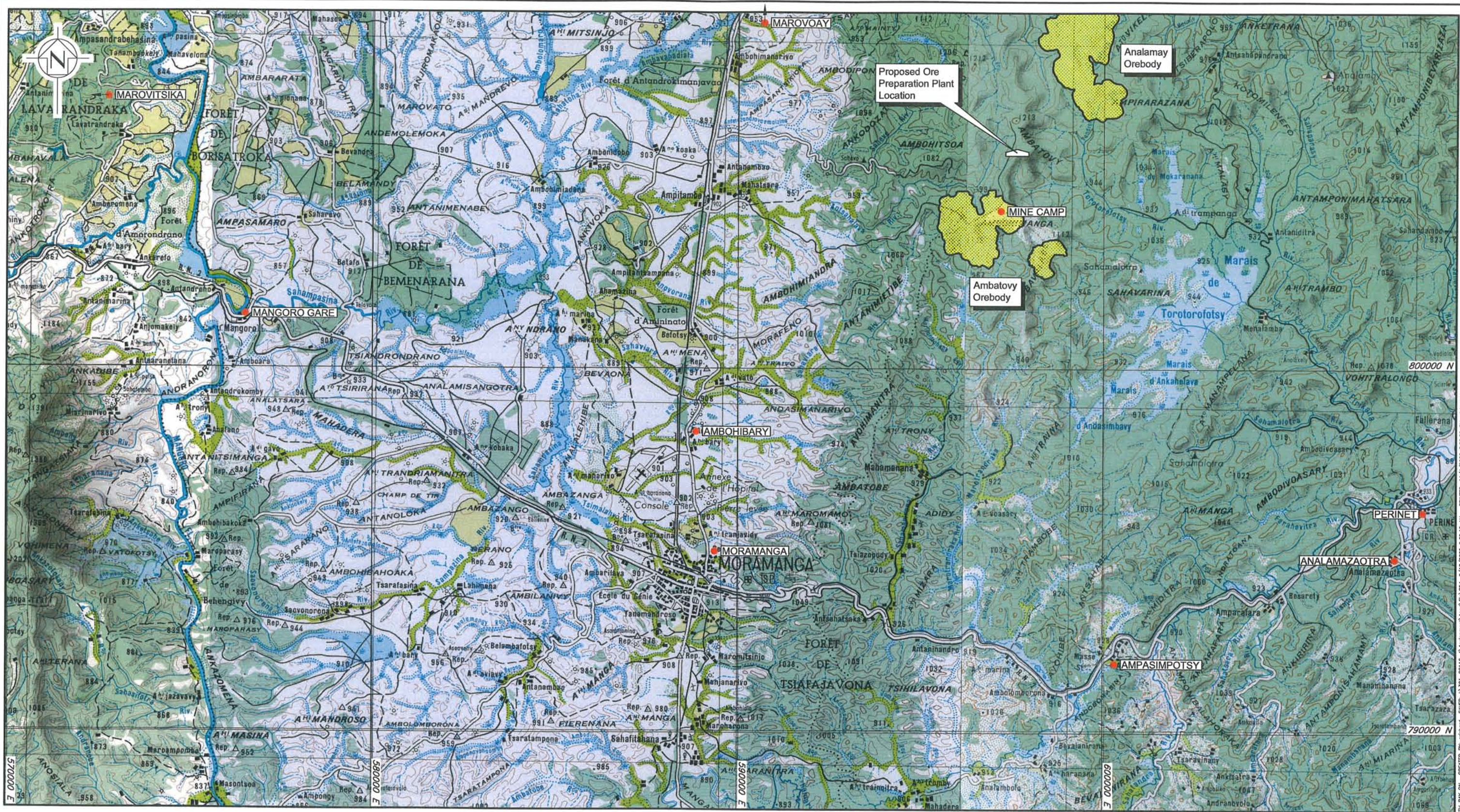
Notes:

1. Ranking Category "Extremely Low" signifies negligible occurrence potential.
2. Details above adapted from Pelletier and Dushnisky (1993) and Davies (1998).

TABLE 4.2
DYNATEC CORPORATION
AMBATOVY PROJECT
REPORT ON NATURAL HAZARDS AND RISK ASSESSMENT FOR THE TAILINGS FACILITY
RELATIVE RISK ASSESSMENT SUMMARY

Natural Hazard Source	Failure Mode (Hazard Outcome)	Consequence	Risk Mitigation through Design	Likelihood of Occurrence Ranking	Consequence Ranking	Overall Risk Rating
1.0 Seismic	1.1 earthquake causing landslide in watershed	a) overtopping of tailings embankment causing release of process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway	2	3	6
		b) breach of tailings embankment causing release of tailings and process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway	1	5	5
		c) overtopping of water pond embankment causing release of process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway	2	2	4
		d) breach of water pond embankment causing release of process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway	1	4	4
	1.2 earthquake causing liquefaction of tailings embankment	a) overtopping of tailings embankment causing release of process water to the environment	Detailed, state of the art geotechnical testing of tailings, fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, design earthquake ground motions and deformations, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)	1	3	3
		b) breach of tailings embankment causing release of tailings and process water to the environment	Detailed, state of the art geotechnical testing of tailings, fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, design earthquake ground motions and deformations, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)	1	5	5
	1.3 earthquake causing liquefaction of water pond embankment	a) overtopping of water pond embankment causing release of process water to the environment	Detailed, state of the art geotechnical testing of tailings, fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, design earthquake ground motions and deformations, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)	1	2	2
		b) breach of water pond embankment causing release of process water to the environment	Detailed, state of the art geotechnical testing of tailings, fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, design earthquake ground motions and deformations, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)	1	4	4
	1.4 tsunami causing erosion of tailings embankment	a) breach of tailings embankment causing release of tailings and process water to the environment	Detailed, state of the art geotechnical testing of tailings, fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, erosion protection measures, embankment freeboard	1	5	5
	1.5 tsunami causing erosion of water pond embankment	a) breach of water pond embankment causing release of process water to the environment	Detailed, state of the art geotechnical testing of tailings, fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, erosion protection measures, embankment freeboard	1	4	4
2.0 Hydrologic	2.1 heavy rain causing landslide in watershed	a) overtopping of tailings embankment causing release of process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway	2	3	6
		b) breach of tailings embankment causing release of tailings and process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway	1	5	5
		c) overtopping of water pond embankment causing release of process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway	2	2	4
		d) breach of water pond embankment causing release of process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway	1	4	4
	2.2 heavy rain causing maximum flows through water pond spillway	a) flooding and damage to downstream resources	Conservative selection of design storm (PMP), inundation studies, storm routing design, spillway design, embankment freeboard	3	3	9
	2.3 heavy rain causing inundation of tailings embankment	a) overtopping of tailings embankment causing release of process water to the environment	Conservative selection of design storm (PMP), inundation studies, storm routing design, spillway design, embankment freeboard	2	4	8
		b) breach of tailings embankment causing release of tailings and process water to the environment	Conservative selection of design storm (PMP), inundation studies, storm routing design, spillway design, embankment freeboard	1	5	5
	2.4 heavy rain causing inundation of water pond embankment	a) overtopping of water pond embankment causing release of process water to the environment	Conservative selection of design storm (PMP), inundation studies, storm routing design, spillway design, embankment freeboard	2	3	6
		b) breach of water pond embankment causing release of process water to the environment	Conservative selection of design storm (PMP), inundation studies, storm routing design, spillway design, embankment freeboard	1	4	4
	2.5 high winds causing large waves at tailings embankment	a) overtopping of tailings embankment causing release of process water to the environment	Conservative selection of design wind (200 km/h), spillway design, embankment freeboard	2	2	4
		b) breach of tailings embankment causing release of tailings and process water to the environment	Conservative selection of design wind (200 km/h), spillway design, embankment freeboard	1	5	5
	2.6 high winds causing large waves at water pond embankment	a) overtopping of water pond embankment causing release of process water to the environment	Conservative selection of design wind (200 km/h), spillway design, embankment freeboard	2	2	4
		b) breach of water pond embankment causing release of process water to the environment	Conservative selection of design wind (200 km/h), spillway design, embankment freeboard	1	4	4
3.0 Geotechnical	2.7 poor geotechnical conditions causing landslide in watershed	a) overtopping of tailings embankment causing release of process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway	2	3	6
		b) breach of tailings embankment causing release of tailings and process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway	1	5	5
		c) overtopping of water pond embankment causing release of process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway	2	2	4
		d) breach of water pond embankment causing release of process water to the environment	Regular inspections and monitoring of hillslopes, completion of maintenance measures, embankment freeboard, spillway	1	4	4
	2.8 poor, unforeseen foundation conditions causing tailings embankment failure	a) minor slump leading to temporary release of tailings and/or process water to the environment	Detailed, state of the art geotechnical testing of tailings, fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)	2	3	6
		b) major slump leading to loss of freeboard and breach of tailings embankment causing major release of tailings and/or process water to the environment	Detailed, state of the art geotechnical testing of tailings, fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)	1	5	5
	2.9 poor, unforeseen foundation conditions causing water pond embankment failure	a) minor slump leading to temporary release of tailings and/or process water to the environment	Detailed, state of the art geotechnical testing of tailings, fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)	2	2	4
		b) major slump leading to loss of freeboard and breach of tailings embankment causing major release of tailings and/or process water to the environment	Detailed, state of the art geotechnical testing of tailings, fill and foundation materials, slope stability analyses, adherence to international standards for acceptable Factors of Safety, embankment freeboard, installation and monitoring of instrumentation, installation and monitoring of drainage structures (embankment and foundation drains)	1	4	4

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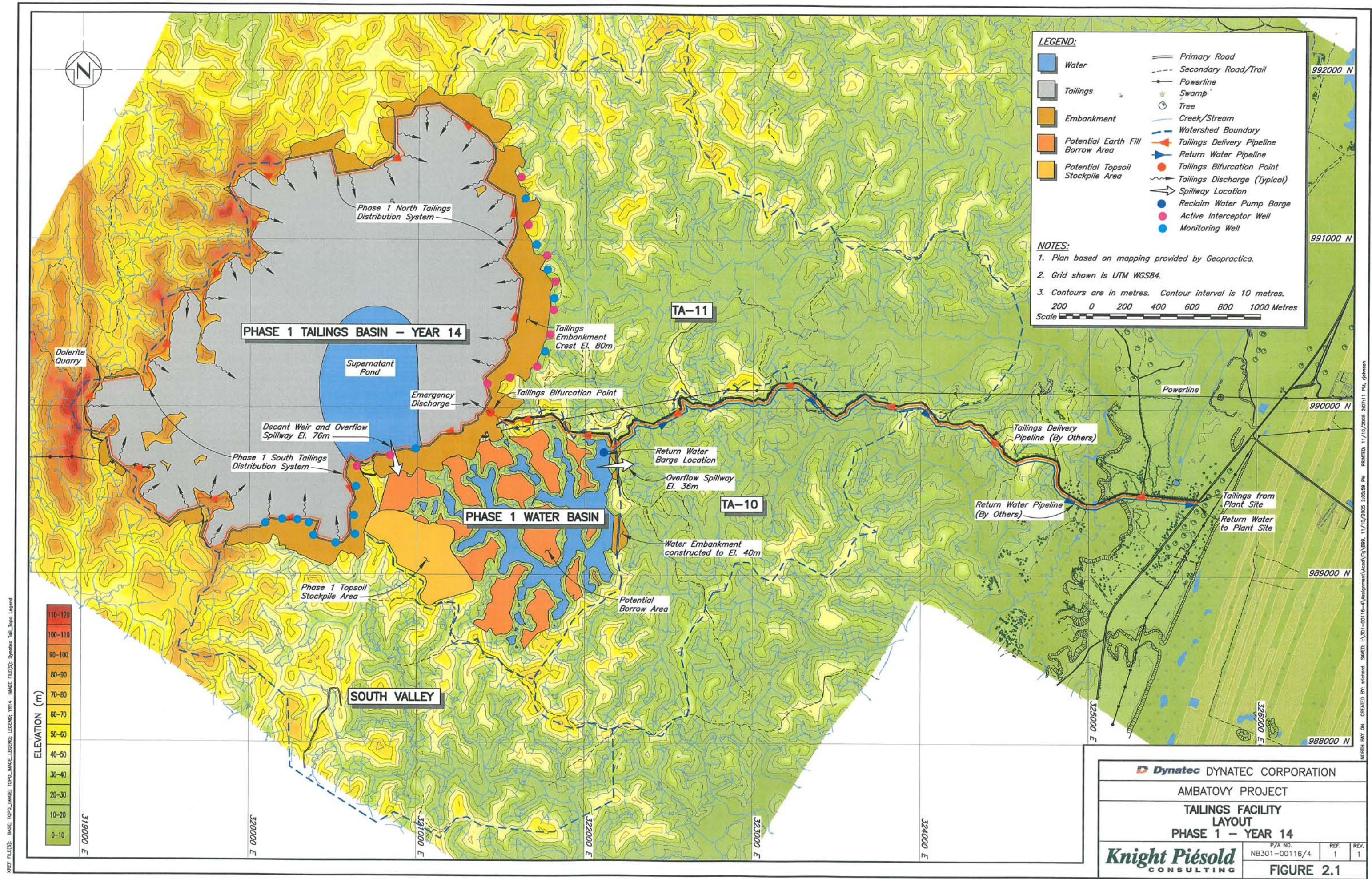
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AMBATOVY PROJECT

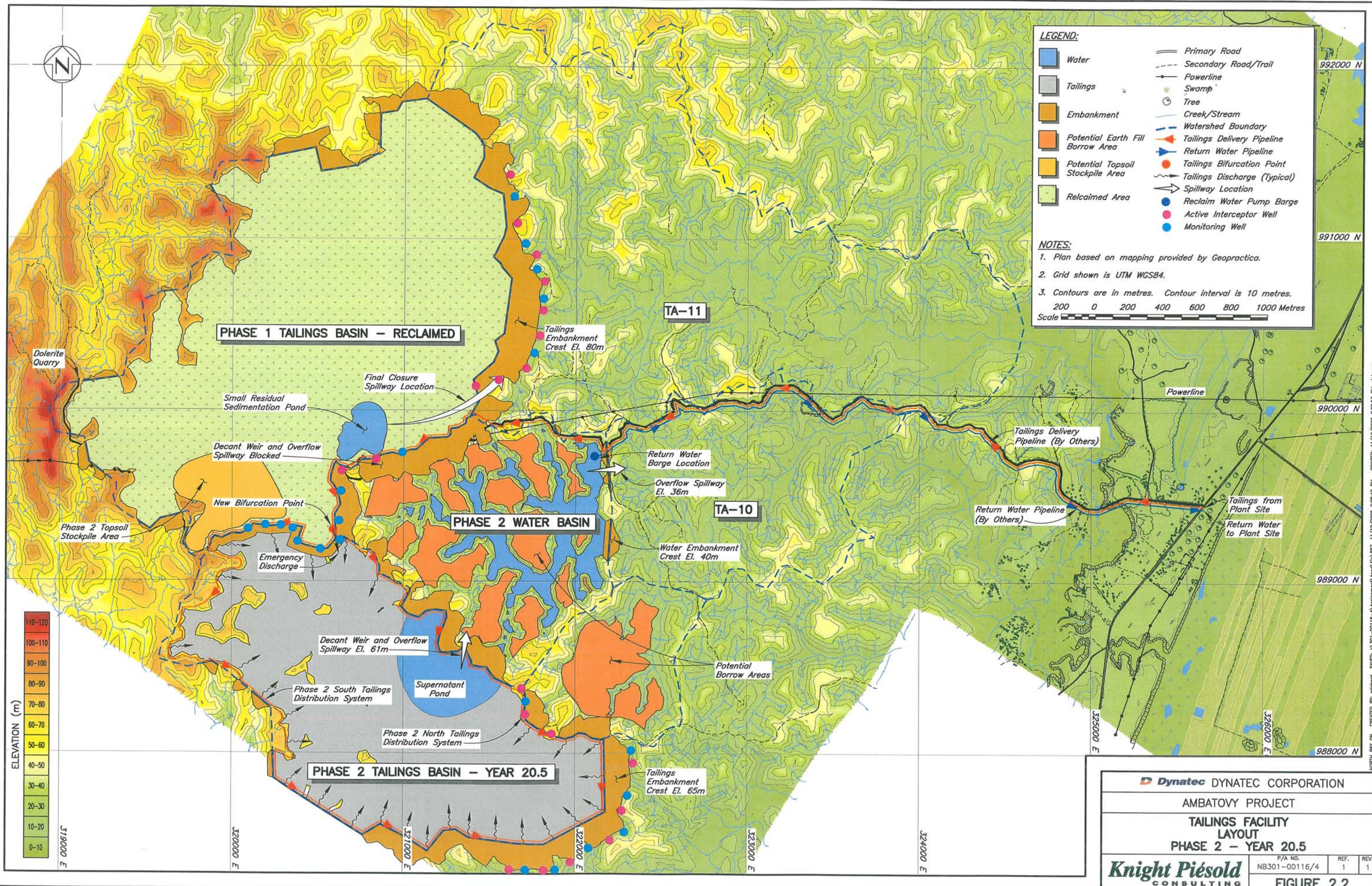
MINE SITE AREA
REGIONAL PLAN

Knight Piésold
CONSULTING

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NB301-00116/4	1	0
FIGURE 1.2		



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AMBATOVY PROJECT

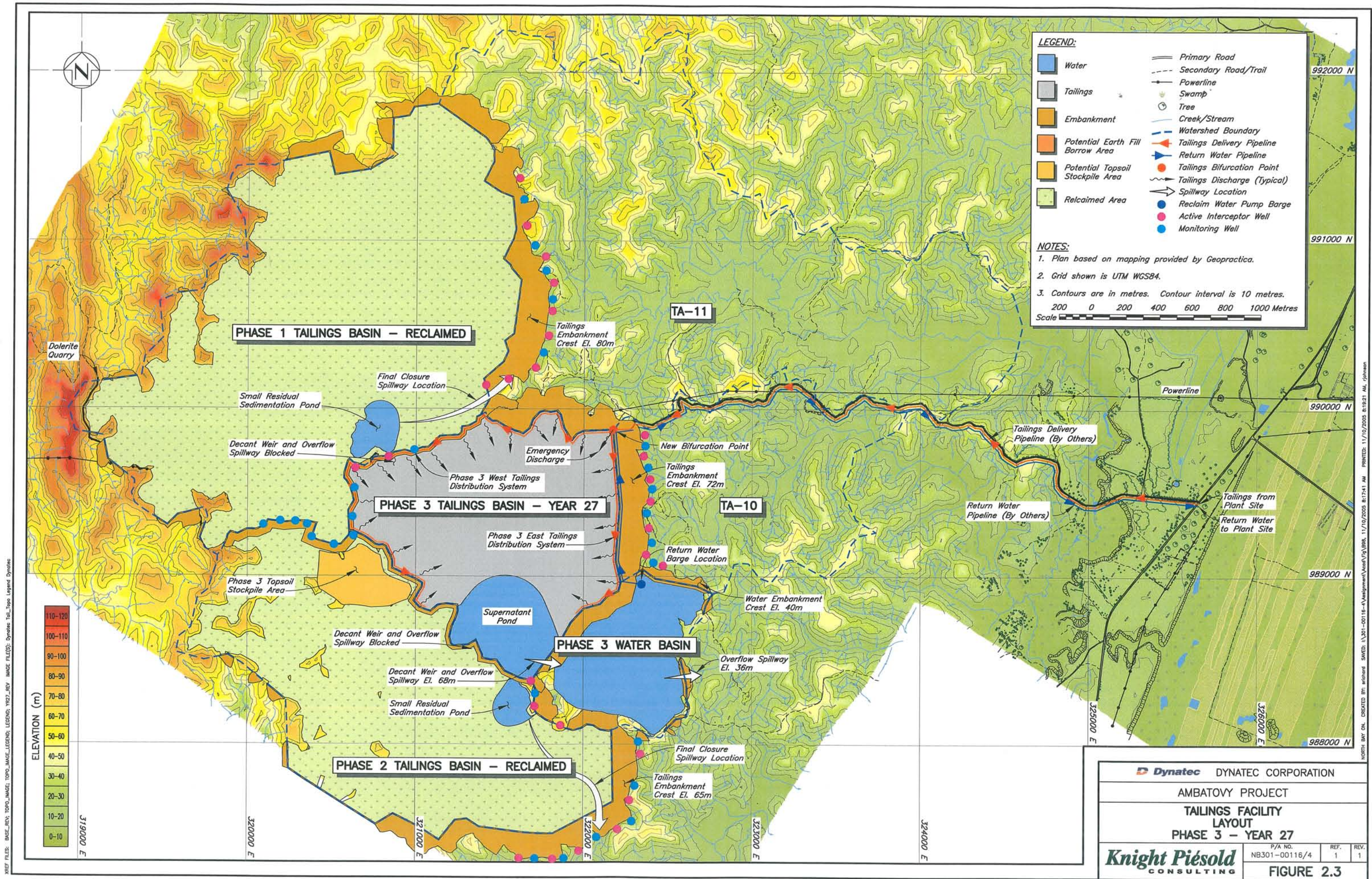
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LAYOUT
PHASE 2 – YEAR 20.5**

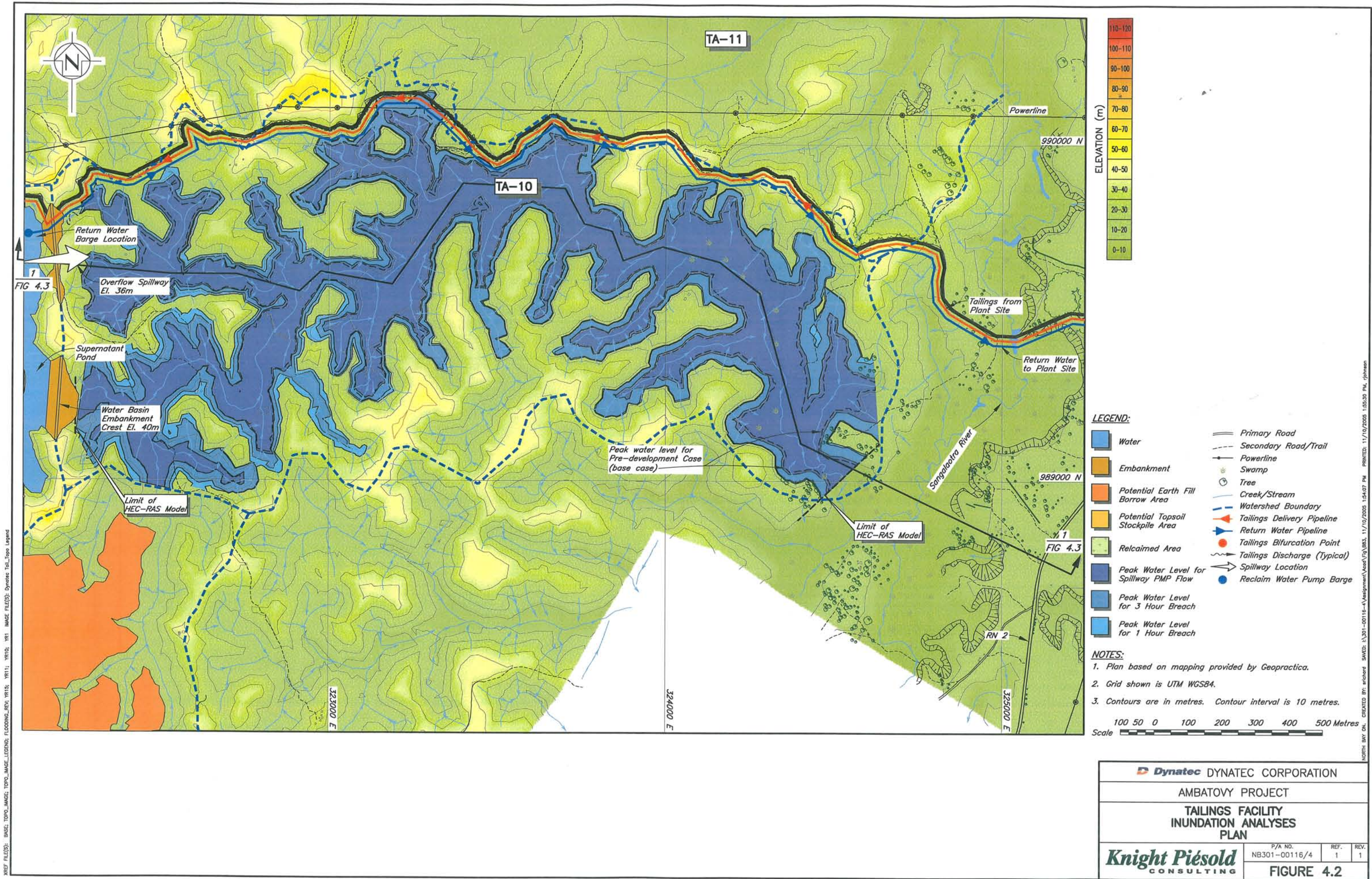
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CONSULTING

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FIGURE 2.2

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APPENDIX A
INUNDATION ANALYSIS

- Memo dated April 18, 2005 regarding Ambatovy Inundation Analysis 19 pages

MODEL INPUTS AND ASSUMPTIONS

River Geometry

River geometry was obtained from detailed topographic mapping specifically obtained for the Ambatovy Project. This mapping was the basis for all channel geometry input in this analysis. The two-metre contour intervals obtained from the topographic mapping were deemed to be sufficiently detailed for the purposes of this study. Figure 1 shows a general plan of the modelled reach.

River cross-sections were specified on the reaches at areas where abrupt changes in channel geometry occurred. This included rapid channel expansions or contractions, significant changes in bank slopes, or at locations of small tributaries. In total, 51 cross-sections were used to define the channel shape including sections that were used to define the earth dam and spillway sections. Cross-sectional spacing was kept consistent throughout each reach, with a spacing range of approximately 40 to 170 metres. Figure 2 shows the cross-section locations used in the study. A general elevation profile of the river is shown in Figure 3.

Spillway Geometry

As construction of the Ambatovy Project will be staged, an operating scenario (or year) had to be selected for the analysis. The scenario selected was an 11-year time horizon (see KPL report NB301-116/2-1, Revision 0), which corresponded to a spillway crest elevation of 36.0m, a spillway wall elevation of 40.0 m, and a peak reservoir outflow of 368 m³/s corresponding to a 6-hour PMP storm duration. A schematic of the spillway geometry input into HEC-RAS is shown on Figure 4.

Dam Geometry and Failure Plane

The earth dam modelled in the analysis was located directly south of the spillway, and was modelled to have a crest elevation of 40 m. Selecting the breach characteristics of the dam is somewhat of a difficult process, as there is much uncertainty over breach geometry, timing and duration. There are some guidelines available indicating expected failure durations, mechanisms and geometries for such inundation analyses. Recommendations from these guidelines (Reference No. 2, 6 and 7), as well as conservative assumptions, were the basis for estimating the breach geometry, timing and duration. Figure 5 shows the dam cross-section, including the breach geometry that was selected for the analysis. The dam was conservatively assumed to fail across its entire width, at the interface of the embankment and the original ground surface. The breach bottom was set at an elevation of 23.5 m.

Failure Duration

Two different dam failure durations were selected for analysis. Initially, a failure duration of 3 hours was selected, but later believed to slightly under-conservative. The analysis was re-run for a shorter failure duration of one hour, to explore the impacts of an accelerated dam failure.

Failure Timing

The timing of the earth dam failure during the scenario was selected to occur during the peak outflow of the PMP storm from the reservoir. The PMP event and dam failure were coupled to produce a flood wave that would inundate the largest conceivable area downstream. This was justified by reasoning that such a large precipitation event might itself cause the dam failure.

Spillway Outflow Hydrograph

The outflow hydrograph from the spillway was determined in a previous study by Dr. W V Pitman (KPL Report NB301-116/2-1, Revision 0). His findings indicated a peak outflow of 368 m³/s from the reservoir. The outflow hydrograph was assumed triangular and symmetrical, over a duration of 6 hours. A graphical representation of the hydrograph is shown on Figure 6.

Manning's "n"

Knight Piésold Ltd. (Vancouver) was unable to obtain any hydraulic or hydrologic data for the Ambatovy Project prior to completing this study. This lack of data required KPL to estimate hydraulic parameters such as Manning's "n" and the antecedent flow conditions in the catchment during the duration of each scenario. The value of Manning's "n" was determined subjectively, but conservatively, through a visual comparison of photographs taken at the site and a literature review regarding various Manning's "n" studies in the US and New Zealand (Reference No. 1 and 3). Based on these photographs and the literature review, the values of Manning's "n" for the floodplain channel and banks are believed to be in the range of 0.1 and 0.2 respectively. Though these values are higher than some sources may indicate, the presence of thick low brush, small trees and rice paddy fields in the river valley is believed to result in a Manning's "n" in this range. Should this be an overestimate of Manning's "n", the result would be an overly impeded flood wave, causing higher flood levels, therefore yielding conservative results with respect to the inundated area. Lower Manning's "n" values would, however, result in faster flood wave travel time. For this reason, these estimates are believed to be conservative, and were assumed to be constant throughout the entire study area. Validation or verification of Manning's "n" may be improved with a more detailed site reconnaissance, however these values vary with flow, and any validation of Manning's "n" values for such a high flow range is nearly impossible, without observing the high flow itself.

Antecedent Flow Conditions

Antecedent flow conditions in the creek were assumed to be in the range of $10 \text{ m}^3/\text{s}$ in both the northern and southern upstream channels, and totalling $20 \text{ m}^3/\text{s}$ in the lower channel. These values may or may not be representative of actual flow conditions in the river prior to and during the PMP event, however it was hypothesized that floods produced by the PMP event and dam break would be far larger than antecedent flows. The results would therefore not be particularly sensitive to small changes in antecedent flows, though this should be verified when streamflow data has been obtained.

Reservoir Stage-Storage Curve

The topographic mapping was also used to compute a stage-storage curve for the reservoir. The curve was a key input to the model, as the data from this curve, combined with the dam breach properties, produced the flood wave for both the dam breach scenarios. The stage-storage curve used for the upstream reservoir is shown on Figure 7.

Expansion/Contraction Coefficients

HEC-RAS also allows the user to input expansion/contraction coefficients to account for energy losses associated with channels of changing cross-section. Default expansion/contraction coefficients of 0.1 and 0.3 respectively were used for the analyses and are believed to be representative, based on the flow regime in the creek.

Tributaries and Ineffective Flow Areas

The detailed topographic mapping utilised in the model showed many small tributaries flowing into the main river channel. For model simplicity, these small tributaries were not modelled directly. The effect that these tributaries may have on the flood was not ignored however. An attempt was made to capture the effects of water storage that the tributaries would contribute as the flood wave propagates downstream. This was modelled by extending some select cross-sections up the tributaries. The portion of the cross-section that was situated outside the main river valley was modelled as an ineffective flow area, therefore having the capability to store water from the flood wave passing by, without contributing to the flow in the main channel.

Summary

A summary of the pertinent input details of each scenario is summarised in Table 1.

RESULTS

The numerical output from HEC-RAS was summarized at three key locations for each scenario. These locations are downstream of the dam (cross-section 40), downstream of the spillway (cross-section 6) and near the end of the modelled reach (cross-section 3). Incremental increases in flow and stage were summarized at these three locations as well as the travel time of the flood wave. A summary of the results for all three scenarios can be found in Table 2.

As shown in Table 2, the spillway scenario (PMP event only) caused an incremental rise in flow of $354 \text{ m}^3/\text{s}$, $2 \text{ m}^3/\text{s}$, and $274 \text{ m}^3/\text{s}$ below the spillway, below the dam and near the floodplain respectively. These incremental flow increases correspond to incremental stage increases of 3.5 m, 2.0 m and 3.3 m respectively. It should be noted that for this scenario, the incremental flow rise in the reach immediately below the dam ($2 \text{ m}^3/\text{s}$) refers to the incremental rise in flow in the downstream direction. The model predicted significant backwater effects up this reach resulting in significant flows in the upstream direction. The net result, as indicated, is an incremental rise in water level of 2.0 m.

The flow and stage increases for the dam breach scenarios were much larger in magnitude, as expected. For the 1-hour breach case, incremental flow rises of $352 \text{ m}^3/\text{s}$, $3254 \text{ m}^3/\text{s}$ and $602 \text{ m}^3/\text{s}$ were computed below the spillway, below the dam, and near the floodplain respectively. These correspond to incremental stage increases of 5.8 m, 14.2 m and 9.5 m respectively. For the 3-hour breach case, slightly lower incremental flow rises of $352 \text{ m}^3/\text{s}$, $1253 \text{ m}^3/\text{s}$ and $518 \text{ m}^3/\text{s}$ were computed below the spillway, below the dam, and near the floodplain respectively. These correspond to incremental stage increases of 3.2 m, 9.7 m and 8.8 m respectively. It should be noted that for this scenario, the incremental flow rise in the reach immediately below the spillway ($352 \text{ m}^3/\text{s}$) refers to the incremental rise in flow in the downstream direction. The model predicted significant backwater effects up this reach resulting in significant flows in the upstream direction. The net result, as indicated, is an incremental rise in water level of 3.2 m.

These results indicate that an extreme hazard exists for any inhabitants and infrastructure located in the study area, downstream of the dam and spillway, should the PMP event and/or a dam failure of such a magnitude exist.

The travel time of the flood peak decreased with increasing peak flood. The travel time of the flood peak for the spillway routing scenario was therefore slowest at $1\frac{1}{2}$ hours (from spillway to cross-section 3), followed by the 3 hour dam failure scenario at 1 hr and 10 minutes (from dam to cross-section 3). The 1 hour dam failure scenario produced not only the highest peak, but the fastest moving flood wave with a travel time of 1 hour from the dam location to cross-section 3, near the floodplain. It should be noted that these times represent the travel time of the flood peak, not the flood wave front.

Several additional figures were prepared to illustrate graphically the increase in stage and flow by location and in time. Figure 8 shows a profile of the modelled reach including the maximum water surface elevations at each cross-section for each scenario. Figure 9 shows the maximum water surface elevations at cross-section 3 (near the floodplain) for each of the scenarios. The hatched area on the left side of the cross-section represents an ineffective flow area, as discussed previously. Figure 10 shows the hydrographs (flow vs. time) for each of the scenarios at cross-section 3. Figure 11 shows stage vs. time for each of the scenarios at cross-section 3.

It was brought to our attention that there was a particular interest in whether or not a significant roadway running in the north-south direction to the east of the study area would be inundated as a result of the PMP event as well as its combination with a dam breach. As the area of concern lies outside of the modelled study area, it is not currently possible to conclude whether or not this roadway would be inundated. However, based on the topography and the flows calculated in the model, a considerable hazard is believed to exist with respect to inundation of the roadway, especially for the dam breach

scenario. In order to reasonably quantify this, however, additional topographic mapping would be required to study a significant tributary that converges with the study reach at the end of the study area (flowing in the north-easterly direction). Further, the study reach also flows into an additional river that flows in the north-south direction. Conditions in this creek would have to be analysed and quantified as well.

CONCLUSIONS

The model indicates that an extreme hazard exists to inhabitants and infrastructure in the valley downstream of the water reservoir (ie the modelled reach) in the event of a PMP storm, and especially in the event of a PMP storm combined with a dam failure. Should only the PMP even occur, water levels could potentially rise 3.5 m, 2.0 m, and 3.3 m below the spillway, below the dam and near the floodplain respectively. Should the PMP event occur in combination with a 3-hour dam breach, water levels could potentially rise by as much as 3.2 m, 9.7 m and 8.8 m below the spillway, below the dam and near the floodplain respectively. If a one-hour breach were to occur, water levels could be expected to rise 5.8 m, 14.2 m, and 9.5 m below the spillway, below the dam and near the floodplain respectively

Given the scope of the current study, it was not possible to accurately quantify the flow and water levels in the floodplain itself, downstream of the study area. In addition, in order to be more conclusive regarding the potential inundation to the roadway east of the study area, further survey analysis is required.

Sincerely,
Thomas Furst, EIT
Staff Engineer

Encl.	Table 1 Rev A	Summary of Input Variables
	Table 2 Rev A	Summary of Results
	Figure 1 Rev A	General Arrangement of Model
	Figure 2 Rev A	HEC-RAS Input Cross Sections
	Figure 3 Rev A	Profile of Modelled River
	Figure 4 Rev A	Spillway Cross Section
	Figure 5 Rev A	Dam Cross Section and Failure Plain
	Figure 6 Rev A	Assumed Spillway Outflow Hydrograph
	Figure 7 Rev A	Stage Storage Curve for Water Reservoir
	Figure 8 Rev A	Maximum River Profile for Each Scenario
	Figure 9 Rev A	Stage vs. Time for Cross-Section No. 3
	Figure 10 Rev A	Hydrographs for Cross-Section No. 3
	Figure 11 Rev A	Stage vs. Time for Cross-Section No. 3

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TABLE 1

**DYNATEC CORPORATION
AMBATOVY PROJECT**

**INUNDATION ANALYSIS
SUMMARY OF INPUT VARIABLES**

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Rev'd Apr/12/05

M:\3\01\00116\04\A\Data\DamBreakStudy\Tables_and_figures.xls\Table 1_rA

Parameter	Spillway Scenario	1 hr Dam Failure Scenario	3 hr Dam Failure Scenario
Baseline flow in Northern Upstream Reach	10 m ³ /s	10 m ³ /s	10 m ³ /s
Baseline flow in Southern Upstream Reach	10 m ³ /s	10 m ³ /s	10 m ³ /s
Baseline flow in Downstream Reach	20 m ³ /s	20 m ³ /s	20 m ³ /s
Duration of Dam Failure	n/a	1 hour	3 hours
Manning's n (main channel)	0.1	0.1	0.1
Manning's n (banks)	0.2	0.2	0.2
Expansion/Contraction Coefficients	0.1/0.3	0.1/0.3	0.1/0.3

Rev A - Issued in draft for memorandum V5-0398

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TABLE 2

DYNATEC
AMBATOVY PROJECT

INUNDATION ANALYSIS
SUMMARY OF RESULTS

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Rev'd Apr/13/05

M:\3\01\00116\04\A\Data\DamBreakStudy\Tables_and_figures.xls]Table 2_rA

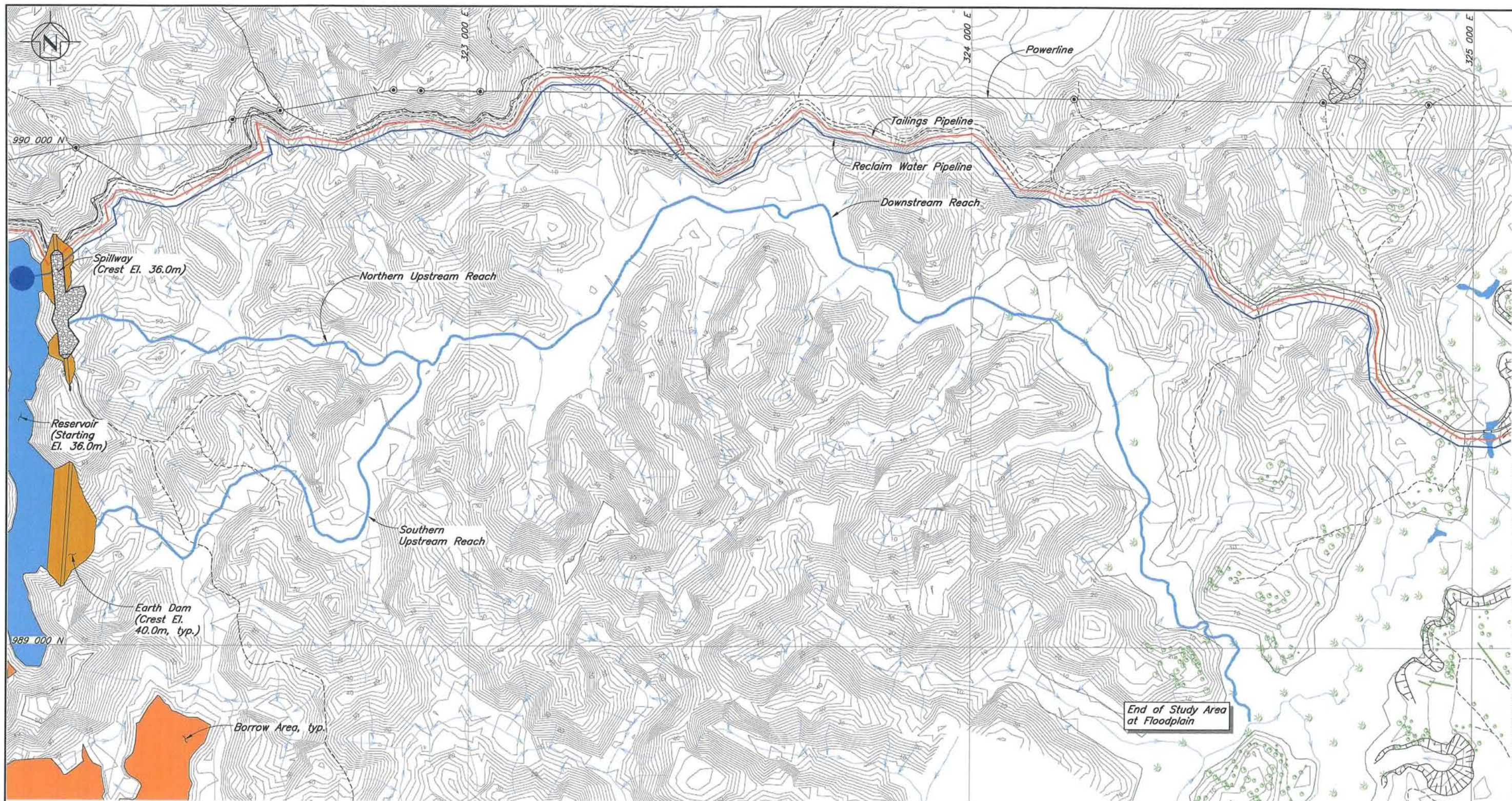
Parameter	Spillway Scenario	1 hr Dam Failure Scenario	3 hr Dam Failure Scenario
Peak incremental flow below spillway (XS 6)	354 m ³ /s	352 m ³ /s	352 m ³ /s
Peak incremental flow below dam (XS 40)	2 m ³ /s	3254 m ³ /s	1253 m ³ /s
Peak incremental flow near floodplain (XS 3)	274 m ³ /s	602 m ³ /s	518 m ³ /s
Peak incremental rise in water level below spillway (XS 6)	3.5 m	5.8 m	3.2 m
Peak incremental rise in water level below dam (XS 40)	2.0 m	14.2 m	9.7 m
Peak incremental rise in water level near floodplain (XS 3)	3.3 m	9.5 m	8.8 m
Flood peak travel time to floodplain	1.5 hours (from spillway)	1 hour (from dam)	1 hour 10 minutes (from dam)

Notes:

1) XS = Cross Section

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A-8



Scale 75 0 75 150 225 300 375 m

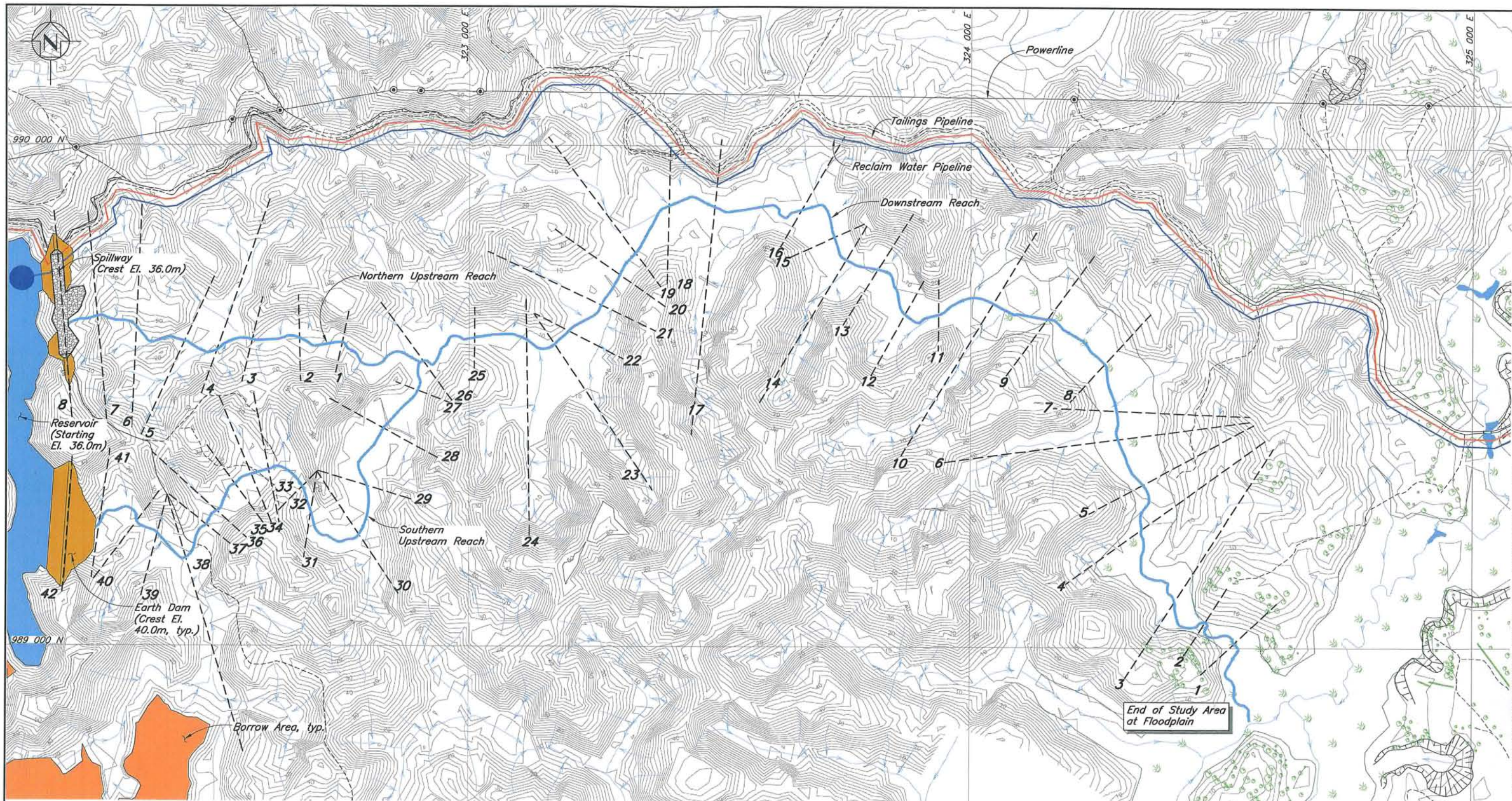
XREF FILE : W11, V15

REV. A 19APR'05 ISSUED IN DRAFT FOR MEMORANDUM V5-0398

Knight Piésold
CONSULTING

PROJECT/ASSIGNMENT NO.	REF. NO.	REV.
NB301-116/4	V5-0398	A

FIGURE 1



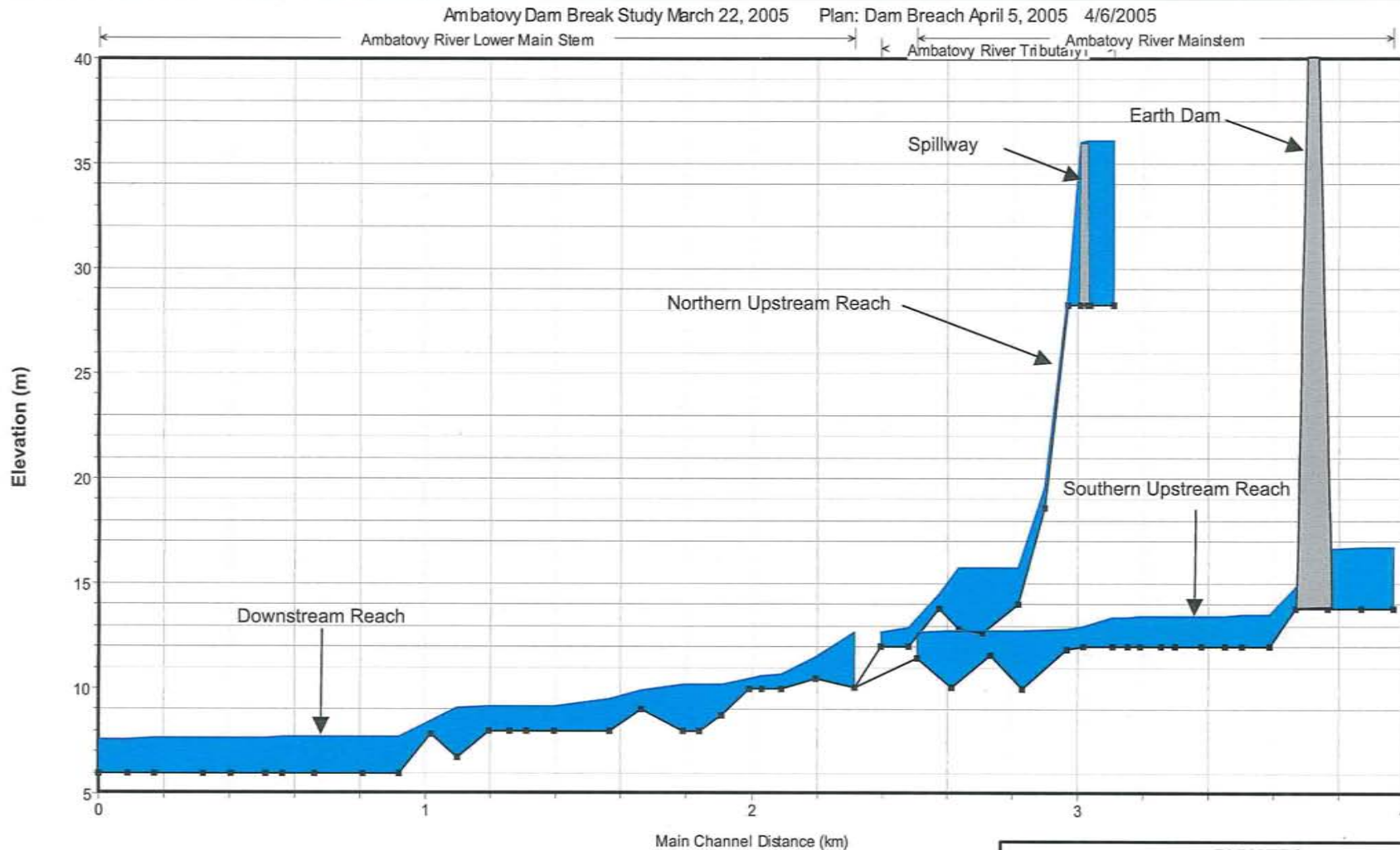
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DYNATEC			
AMBATOVY PROJECT			
INUNDATION ANALYSIS HEC-RAS INPUT CROSS-SECTIONS			
Knight Piésold CONSULTING	PROJECT/ASSIGNMENT NO.	REF. NO.	REV.
	NB301-116/4	V5-0398	A
FIGURE 2			

XREF FILE : W11, W15

REV. A 19APR'05 ISSUED IN DRAFT FOR MEMORANDUM V5-0398

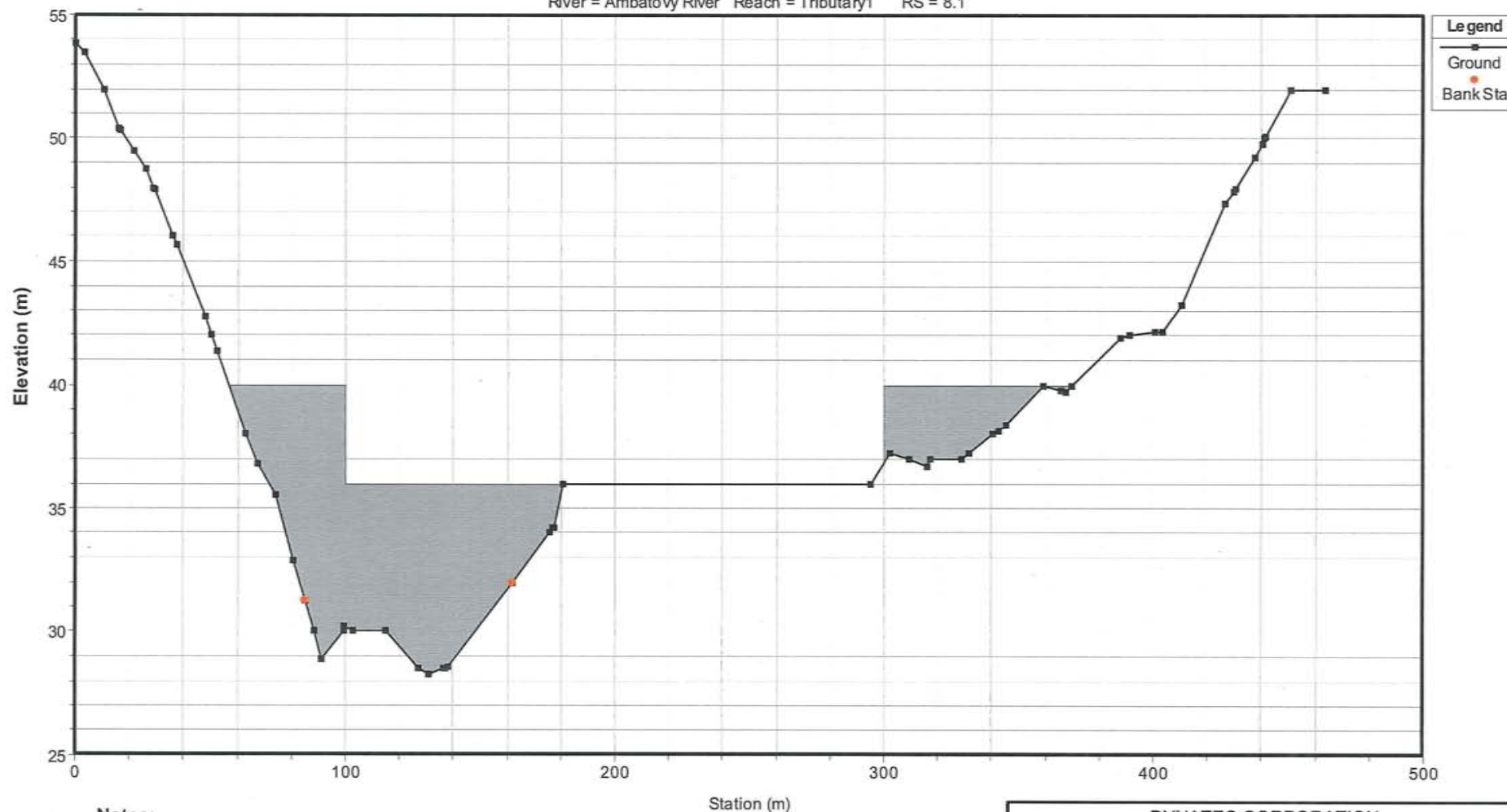
CAD FILE: W:\301\00116\04\VA\KCSA\FigA\B02.dwg 1:7500 PLOT 1-1 (PS) Apr 19 2005 by:mbh/afw Time: 13:30 VANCOUVER B.C.



DYNATEC			
AMBATOVY PROJECT			
INUNDATION ANALYSIS			
PROFILE OF MODELLED RIVER			
Knight Piésold CONSULTING	PROJECT / ASSIGNMENT NO.	REF NO.	REV.
	NB301-116/4	V5-0398	A
FIGURE 3			

Ambatovy Dam Break Study March 22, 2005 Plan: April 6, 05 - Spillway 4/11/2005

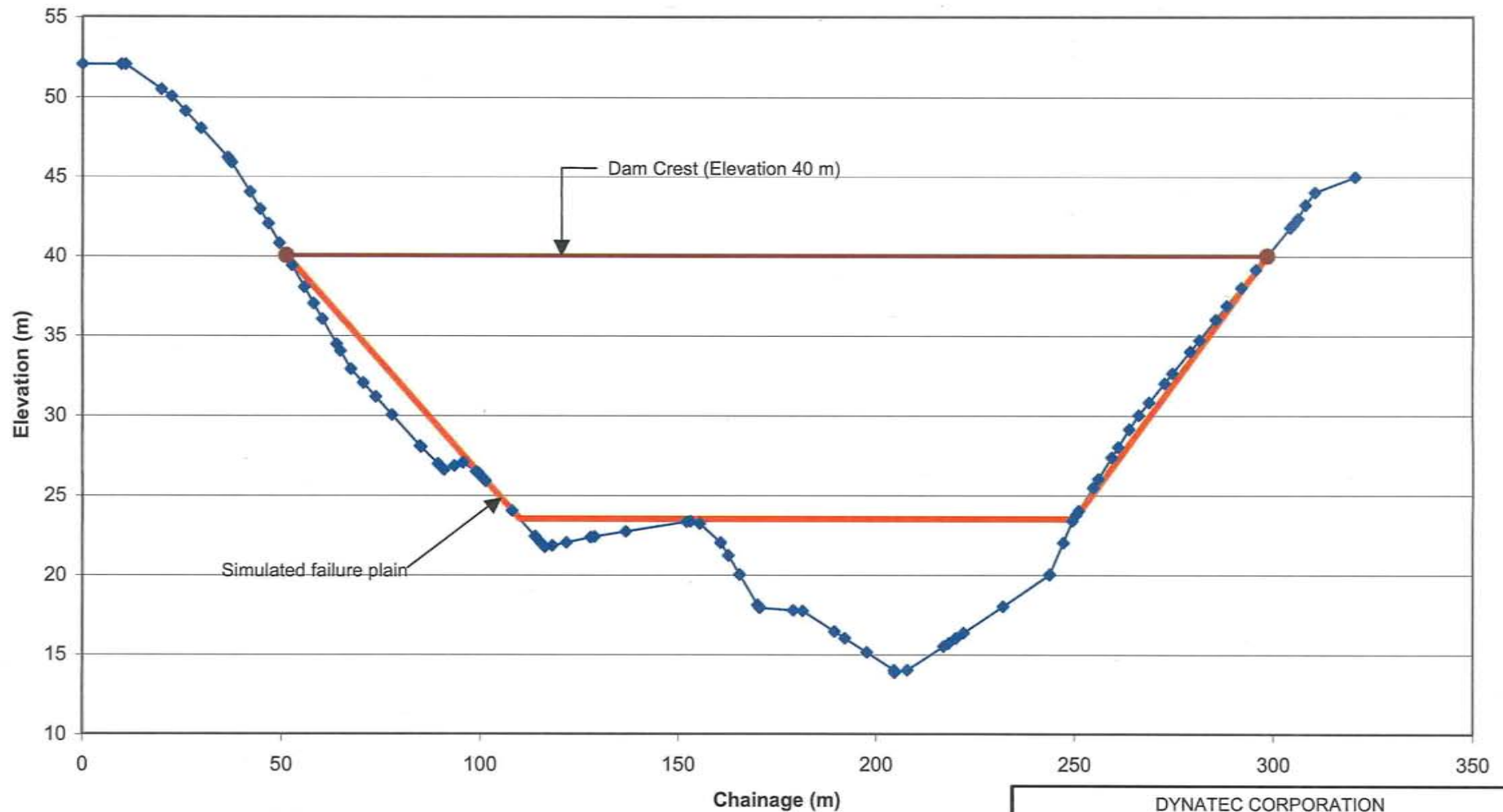
River = Ambatovy River Reach = Tributary1 RS = 8.1



Notes:

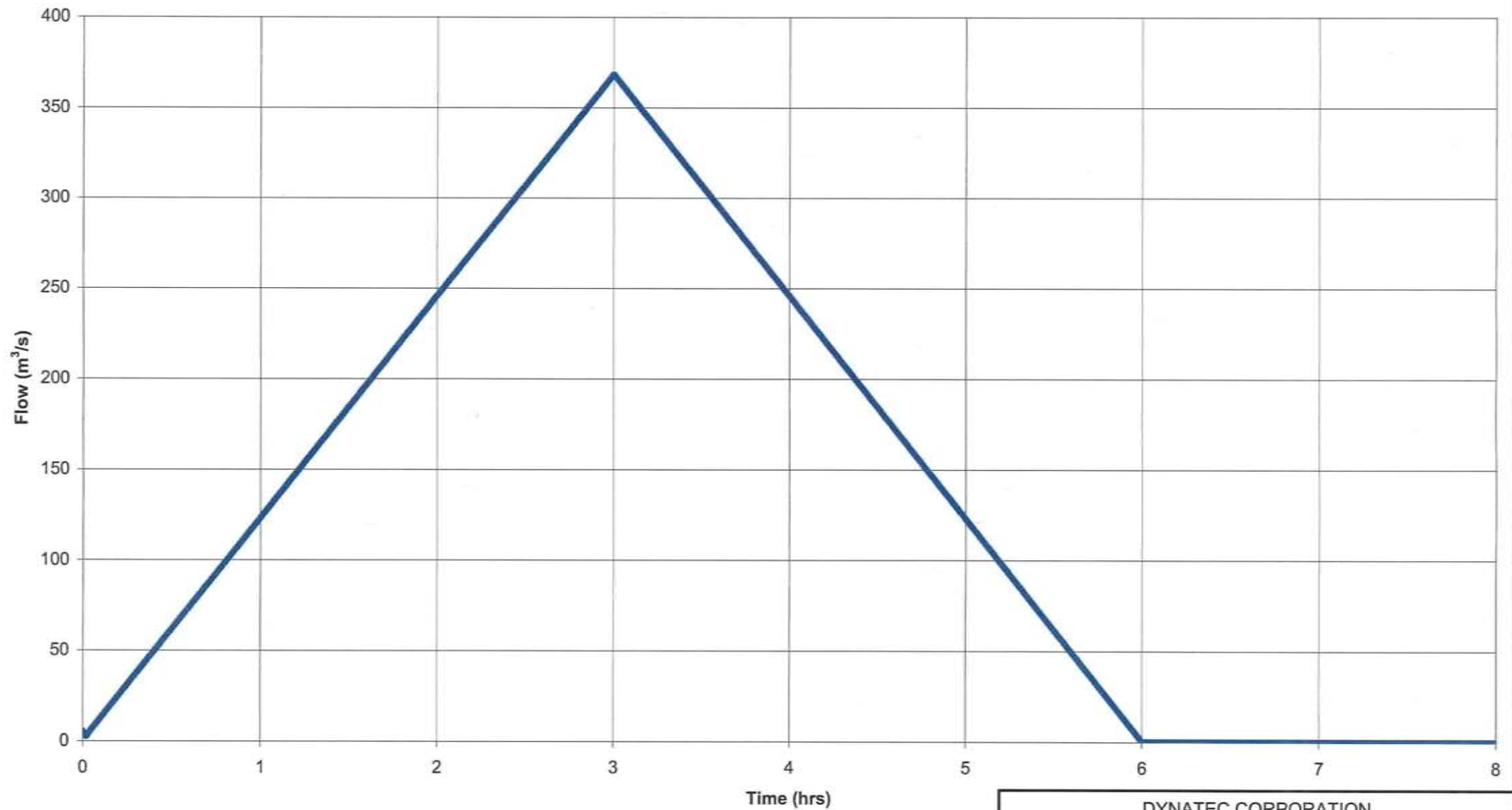
- 1) Cross-section facing downstream direction

DYNATEC CORPORATION			
AMBATOVY PROJECT			
INUNDATION ANALYSIS			
SPILLWAY CROSS-SECTION			
Knight Piésold CONSULTING	PROJECT / ASSIGNMENT NO.	REF NO.	REV.
	NB301-116/4	V5-0398	A
FIGURE 4			

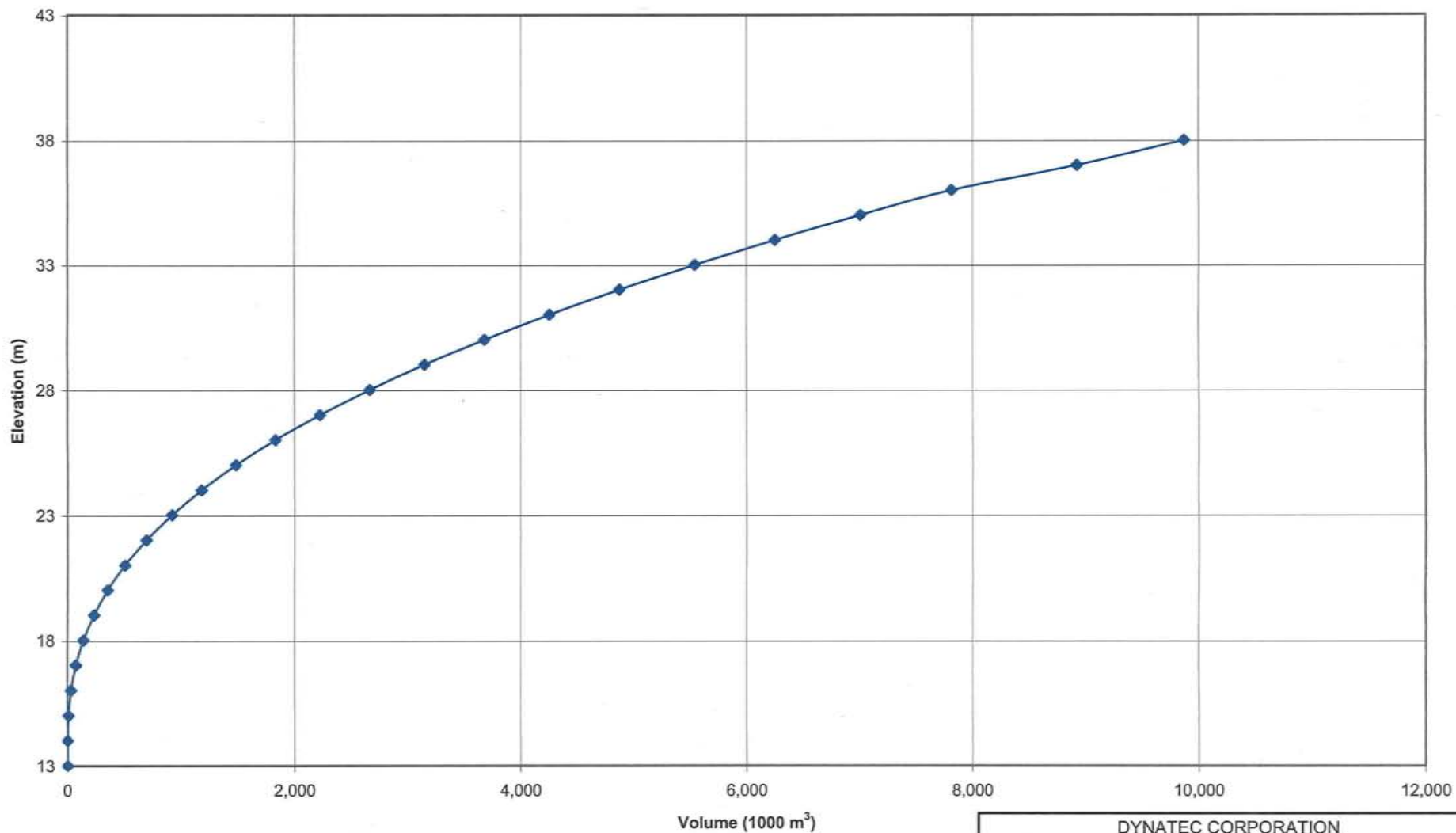


DYNATEC CORPORATION			
AMBATOVY PROJECT			
INUNDATION ANALYSIS			
DAM CROSS-SECTION AND FAILURE PLAIN			
Knight Piésold CONSULTING	PROJECT / ASSIGNMENT NO.	REF NO.	REV.
	NB301-116/4	V5-0398	A
FIGURE 5			

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DYNATEC CORPORATION			
AMBATOVY PROJECT			
INUNDATION ANALYSIS			
ASSUMED SPILLWAY OUTFLOW HYDROGRAPH			
Knight Piésold CONSULTING	PROJECT / ASSIGNMENT NO.	REF NO.	REV.
	NB301-116/4	V5-0398	A
FIGURE 6			



DYNATEC CORPORATION
 AMBATOVY PROJECT
 INUNDATION ANALYSIS

STAGE STORAGE CURVE FOR WATER RESERVOIR

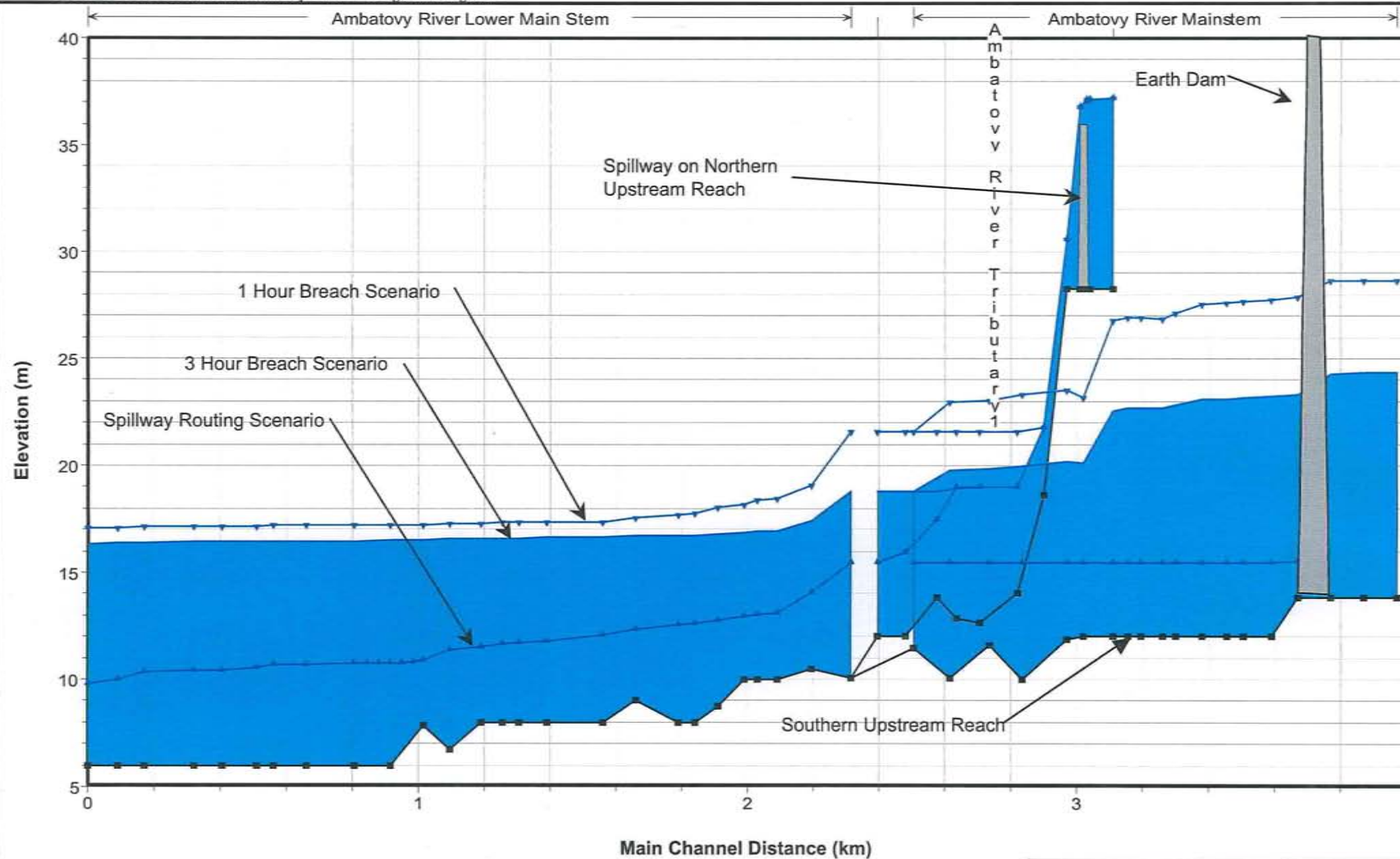
Knight Piésold
 CONSULTING

PROJECT / ASSIGNMENT NO. NB301-116/4	REF NO. V5-0398	RE V
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FIGURE 7

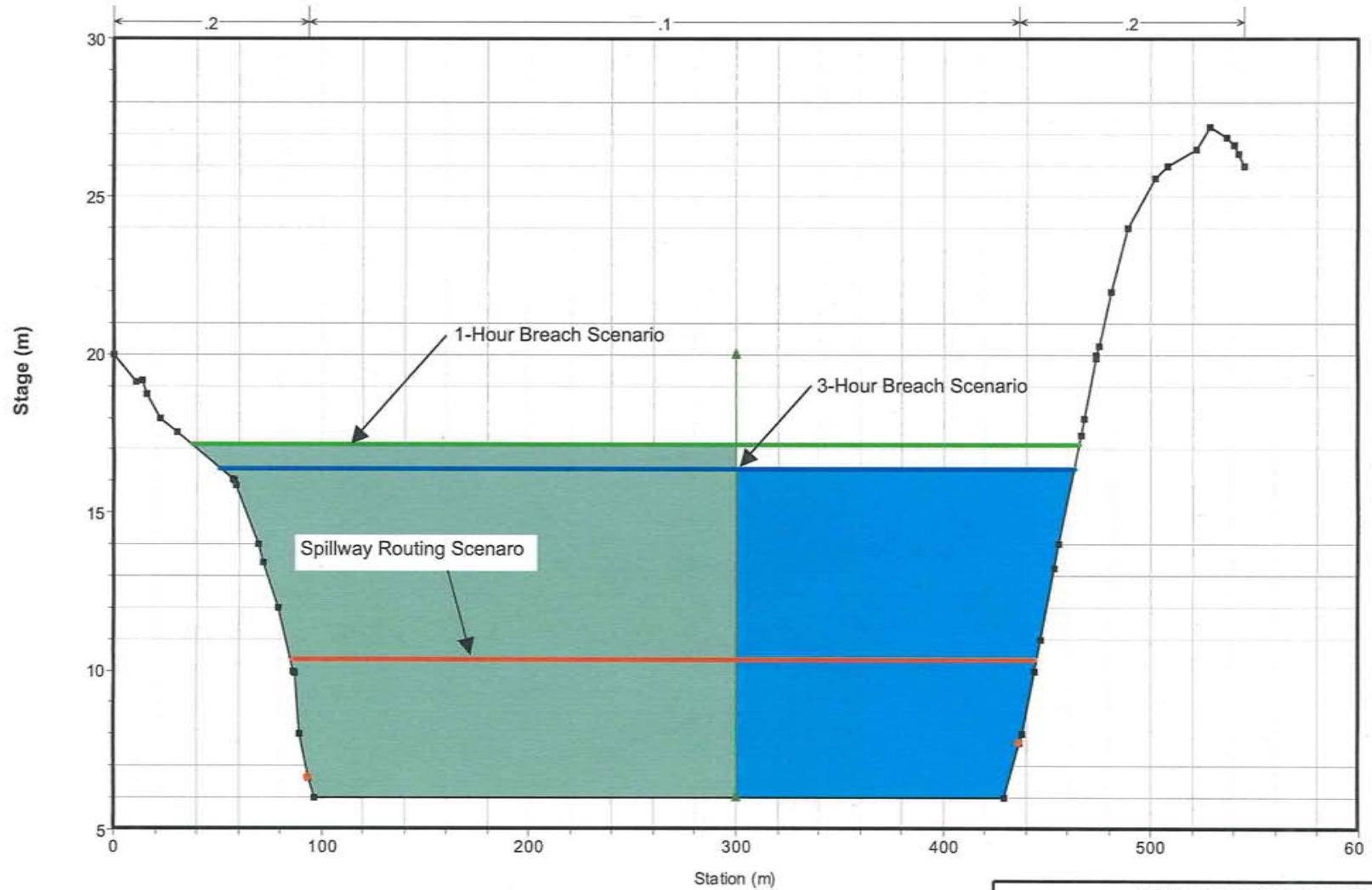
A-15

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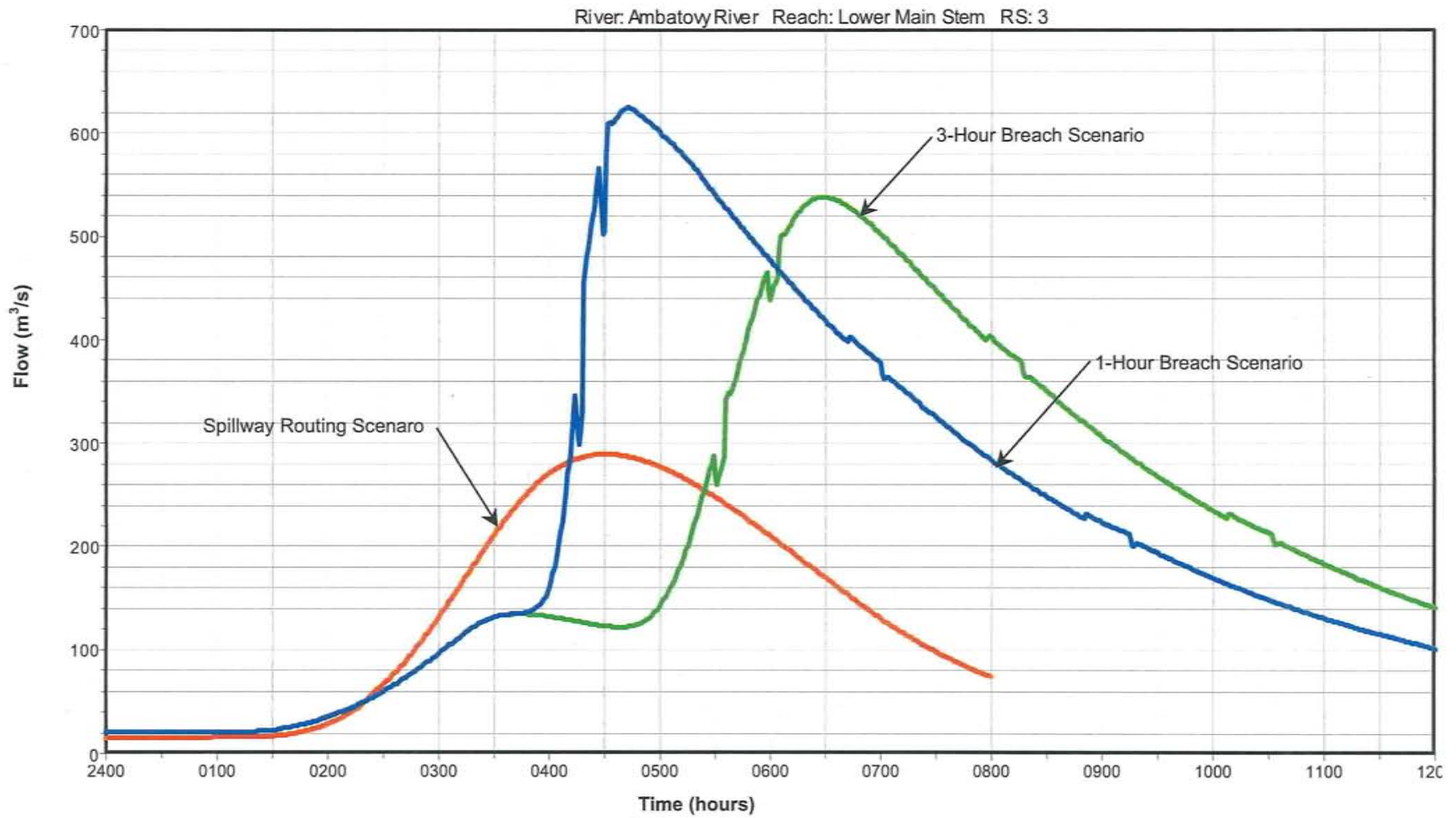
DYNATEC CORPORATION			
AMBATOVY PROJECT			
INUNDATION ANALYSIS			
MAXIMUM RIVER PROFILE FOR EACH SCENARIO			
Knight Piésold CONSULTING	PROJECT / ASSIGNMENT NO.	REF. NO.	REV.
	NB301-116/4	V5-0398	A
FIGURE 8			

A-16

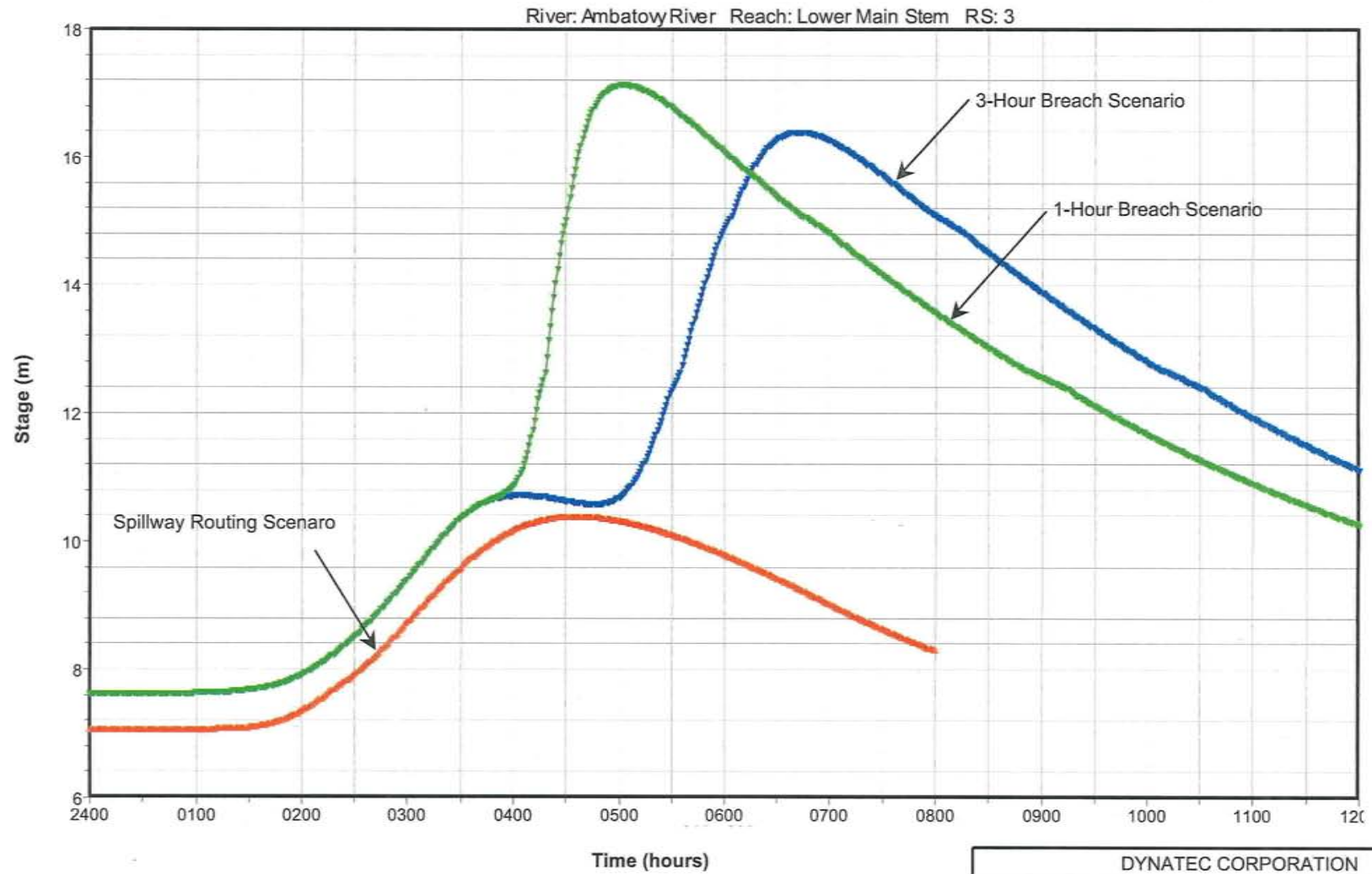


DYNATEC CORPORATION			
AMBATOVOY PROJECT			
INUNDATION ANALYSIS			
STAGE VS. TIME FOR CROSS SECTION No. 3			
Knight Piésold CONSULTING	PROJECT / ASSIGNMENT NO.	REF NO.	REV
	NB301-116/4	V5-0398	A
FIGURE 9			

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DYNATEC CORPORATION			
AMBATOVY PROJECT			
INUNDATION ANALYSIS			
HYDROGRAPHS FOR CROSS-SECTION No. 3			
Knight Piésold CONSULTING	PROJECT / ASSIGNMENT NO.	REF NO.	REV.
	NB301-116/4	V5-0398	A
FIGURE 10			



DYNATEC CORPORATION			
AMBATOVY PROJECT			
INUNDATION ANALYSIS			
STAGE VS. TIME FOR CROSS SECTION No. 3			
Knight Piésold CONSULTING	PROJECT / ASSIGNMENT NO.	REF NO.	REV
	NB301-116/4	V5-0398	A
FIGURE 11			

VOLUME I

APPENDIX 6.1

ATTACHMENT 5

TSUNAMI THREAT MEMORANDUM



Appendix 37 **Tsunami Study**

Tsunami threat to Madagascar Coast

Tsunami threat to Madagascar Coast

February 14, 2005

Mr. Michel Weiss
SNC-Lavalin Engineers & Constructors Inc.
2200 Lake Shore Blvd. West
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Canada, M8V 1A4

W.F. Baird & Associates
Coastal Engineers Ltd.
1145 Hunt Club Road, Suite 500
Ottawa, Ontario, K1V 0Y3
Telephone: 613 731-8900
Fax: 613 731-9778

Baird

Dear Mr. Weiss:

Re: Tsunami threat to Madagascar Coast near Tamatave

Baird & Associates was retained by SNC-Lavalin to carry out a preliminary assessment of the potential tsunami inundation hazard for a proposed industrial facility under development near Tamatave on the east coast of Madagascar. This study was precipitated by the tsunami event of December 26, 2004 that resulted in widespread destruction throughout the Indian Ocean basin.

Introduction

SNC-Lavalin is participating in the design and construction of a proposed nickel processing facility to be located 10 km south of the port of Tamatave, Madagascar. The processing plant will be situated approximately 2 km inland of the shoreline and will encompass a site with approximate dimensions of 1 km by 1 km. In addition to the processing facility, a jetty will be constructed from the shoreline into water depths of approximately 22 metres for the berthing of vessels delivering ammonia, fuel oil and other products necessary for plant operations. An ammonia receiving station, which consists of a number of storage tanks, will be located at the shoreline termination of the jetty. The receiving station is to be connected by means of buried pipeline to the processing plant.

A preliminary assessment of tsunami inundation threat for the proposed development has been carried out. The following tasks were performed in this study:

1. A review of the proposed SNC development.
2. A review of available data concerning the impact of the December 26, 2004 tsunami on Madagascar.
3. A review of the technical literature and databases on sources of historical tsunamis in the Indian Ocean.
4. A preliminary assessment of tsunami risk at the project site, based on the historical data and the site information.
5. An outline of proposed tasks for future, more comprehensive studies, should SNC require a more detailed assessment.

This letter provides a brief summary of the methodology and findings of our investigation.

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Tsunami Generation and Propagation

A tsunami is a water wave typically created by a large-scale disturbance of the ocean surface. Most tsunamis are the result of the displacement of the seabed through seismic activity, although submarine landslides and violent volcanic eruptions can also trigger tsunamis. The most destructive tsunamis are created by large, shallow earthquakes that have a fault line at or near the seabed. It is important to note that these types of seismic disturbances are usually created in regions of the earth characterized by *tectonic subduction* along tectonic plate boundaries. In a subduction zone, one of the tectonic plates is sliding beneath the adjacent plate. Energy builds up in the fault line between the plates that eventually is released in an earthquake, which can tilt, offset, or displace large areas of the ocean floor from a few kilometers to as much as a 1,000 km or more.

Tsunamis generated by landslides or volcanic eruption can also be very destructive, although generally in a small region surrounding the point of disturbance. These tsunamis tend to disperse rapidly in the open ocean and do not result in basin-wide disturbances.

A tsunami is composed of several very long waves that propagate away from the zone of disturbance in all directions. These waves have very long periods (5 minutes to 100 minutes) and length (hundreds of kilometers), travel at high speed, but have a relatively low amplitude in the deep ocean. Even some of the most destructive tsunamis have had a wave height of less than 1 metre in the open ocean.

The destructive effect of a tsunami is due to the *shoaling* of the waves as they propagate into shallow water adjacent to coastlines. As water depths reduce near shore, the tsunami wave begins to slow and reduce significantly in length. The wave energy is directed upwards and the wave begins to grow considerably in height. For example, a tsunami wave that has a height of one metre in deep water offshore can develop to a height of 30 metres or more at the shoreline, referred to as the tsunami *runup*. Runup is the maximum vertical distance above sea level achieved by the tsunami wave.

Tsunami waves follow the same principles of transmission as wind-generated waves in the ocean, albeit at a different scale. In addition to shoaling, the waves refract (change direction in response to water depth), diffract (spread behind an obstacle), and break much like other ocean waves.

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The Event of December 26, 2004

The tsunami of December 26, 2004 in the Indian Ocean was a severe event that was likely the largest basin-wide event in the Indian Ocean in well over 100 years. The 9.0 magnitude earthquake that caused this tsunami was associated with a subduction fault off the coast of Sumatra, which was at a shallow depth below the floor of the ocean. The earthquake resulted in significant vertical displacement of the seabed over a large area and created the generation mechanism required for the large-scale tsunami that would propagate throughout the Indian Ocean. Documentation from this event is still preliminary, but it is likely that localized runup may have reached 20 to 30 m at locations near the epicenter. There are preliminary water level observations from countries in the vicinity of Madagascar, including:

- Tidal records from the Seychelles and Mauritius are presented in Figures 1 and 2, respectively. Both these locations exhibited water level fluctuations in the order of 2.5 m, with a maximum runup about 1.5 m above the normal level.
- Reports from Mozambique and Kenya (estimates, not gauge records) indicate that the runup was in the range of 1 m, although many media reports indicate values higher than this. This difference may be due to varying nearshore dynamics in different regions.
- A tide gauge record in Aden suggests a wave of about a 40 cm.

The U.S. National Oceanic and Atmospheric Administration (NOAA) has simulated the December 2004 tsunami using a numerical model, and assessed maximum wave heights at locations throughout the Indian Ocean. The NOAA model was validated both against tidal gauge measurements as well as by means of satellite altimetry measurements, as three different satellites passed over the Indian Ocean following the event. Two of these records are shown in Figures 3 and 4, and indicate a wave height (trough to crest) in the open ocean of about 1 m. Indications from this model are that the maximum wave height in the region offshore from Madagascar was in the order of 0.1 to 0.2 m, as shown in Figure 5. Using the simplified method of Synolakis (1987) for the estimation of runup of solitary waves on smooth slopes, the maximum tsunami runup at the coastline of the proposed project site was estimated to be in the range of 1 to 2 metres.

Both formal and informal requests to the Madagascar Government to obtain data on tsunami impacts along the coastline of Madagascar were not successful; however, anecdotal observations were provided by residents in Fort Dauphin on the southeast coast of Madagascar (Baird is currently designing a project in this region). Reports from this location indicated that the ocean water level dropped by approximately 1 m

at the onset of the tsunami, followed by an increase in the water level of about 1 metre, ten minutes later. This would correspond to a total height of about 2 m and is in agreement with observations from Mauritius and the Seychelles.

Assessment of Historical Tsunami Events in the Indian Ocean

The National Geophysical Data Center (a branch of NOAA in the United States) maintains a database of historical global tsunamis, including documentation of the generation mechanism and the severity of the tsunamis. This database was searched for the Indian Ocean region for a time period covering recorded history and the results mapped in a Geographic Information System. Figure 6 presents the epicenter locations and earthquake magnitude for seismic disturbances that resulted in identified tsunamis, while Figure 7 shows source disturbance location for identified tsunami events, ranked on the basis of tsunami intensity (magnitude of the tsunami created). It may be noted that the majority of the disturbances have originated in the vicinity of Indonesia, a considerable distance from Madagascar.

The larger events in the database were investigated in greater detail. The following events contained documented cases where the runup from the tsunami was observed at locations close to Madagascar:

- Volcanic Eruption of Krakatua, August 27, 1883. This event caused a tsunami that had documented runup in the order of 20 to 30 m in regions close to the site between the islands of Java and Sumatra. Recordings in regions in the vicinity of Madagascar were considerably less, with values in Mauritius, the Seychelles Islands and the coast of Africa ranging from 30 to 60 cm in height. Note that these heights are heights measured near the shore, not in the open ocean.
- Arabian Sea earthquake, November 27, 1945. This event was an earthquake with a magnitude of 8.3 near the coast of the Pakistan/Iran border. Local runup heights of about 15 m were measured in Pakistan, while in the Seychelles, only 30 cm was recorded.
- An earthquake in Diego Garcia in 1983 created a tsunami of about 1.5 m, in the local region. This event was recorded in the Seychelles with an approximate nearshore height of 10 to 40 cm in height.

There is very little other information in the technical literature on the occurrence and impacts of Indian Ocean tsunamis. Murty and Babty (1999) reviewed the historical impact of tsunamis on the coastline of India. They identified the occurrence of four

different events since 1883, including the first two events listed above, as well as an 1884 earthquake in the Bay of Bengal (east of India) and a 1941 event in the Andaman Sea.

The following conclusions may be drawn from the available data and technical literature:

- In the past 125 years, there have only been four to six events of a magnitude sufficient to generate a measurable (greater than a few centimeters) tsunami wave along the eastern shoreline of Madagascar.
- Except for the Diego Garcia 1983 event, which was a localized tsunami, all of the historical tsunamigenic events have occurred at a considerable distance from Madagascar, primarily originating along the Indonesian coastline.
- It is probable that the 2004 Indian Ocean tsunami is the largest tsunami incident to the eastern shoreline of Madagascar to have occurred in recent history (greater than 125 years).

Future Tsunami Threat to the Project Site

Earthquakes are inherently unpredictable; however, the global zones of seismic activity are well established. The large tsunami-generating earthquakes in the Indian Ocean are associated with the subduction (convergent) type of fault line that exists near Sumatra. Faults closer to the site may have earthquakes but would not produce tsunamis in the manner that the subduction fault does. Figure 8 shows the tectonic plates in the region and provides an indication of the type of fault that exists along each boundary. The only other subduction plate in the region is off the coast of Iran and Pakistan where the tsunami event occurred in 1945. Figure 9, which indicates the locations of earthquakes that resulted in measured tsunami runup, supports these observations. The fault pattern on the ocean floor is further evidence of the different types of boundaries that exist in the central part of the Indian Ocean compared to the eastern margin.

As may be noted in Figure 8, there is a tectonic plate boundary to the east of Madagascar; however, this is a divergent boundary where the plates are pulling apart.

Given the historical data and the geological evidence, it is probable that future tsunamigenic events of significant intensity will originate in these subduction zones at considerable distance from Madagascar. Tsunami waves disperse with distance (this may be noted in Figure 5), thus there will be a limit to the size of tsunami that can

Baird

potentially impact the eastern shorelines of Madagascar. The December 26, 2004 tsunami appears to represent an event with a low probability of occurrence (i.e. a return period well over 100 years).

We note, however, that the December 2004 tsunami originated at the northern end of the subduction zone. It is possible that the southern end of subduction zone may release and cause a significant tsunami during the design life of the proposed project. Such an event, if of the magnitude of the 2004 tsunami, may cause greater runup (1.5 to 2 times) along the eastern shores of Madagascar than that witnessed in 2004 due to the more direct propagation distances to the site. Such an event might result in wave runup in the order of 3 to 4 metres.

Other possible causes of tsunamis that are much more local include underwater landslides. Available bathymetric charts do not provide sufficient information to identify potentially unstable areas. Since these events are rare and the tsunami impacts are typically more localized, it is difficult to determine their potential probability.

Assessment of the Project Site

The processing facility is shown as being located approximately two kilometers inland of the shoreline in a region where elevations are in the order of 5 or 6 m above sea level. For a tsunami to reach this location, it would need to have a sustained (several minutes) crest level of over 5 metres to allow water to move inland such a distance. It is likely that in an event such as this, water would flow up the canal from the Ivondro River. The lowest elevation path between the coast, river or canal would be the path of approach for the water.

The nearshore bathymetry is relatively consistent and it is not anticipated that this bathymetry would result in unusual amplification of a tsunami wave.

Based on the information compiled for this study, it appears that there has not been a case where tsunami inundation has reached the processing plant site in the past 125 years and, potentially, in recorded history.

Even if a tsunami of twice the amplitude of the 2004 event were to occur in the future, it appears unlikely that it would cause inundation of the processing plant (based on the simplistic calculations that were performed).

In contrast, the proposed coastal facilities (jetty and receiving station) would be subject to tsunami effects and should be designed accordingly. In particular, the high current velocities associated with a tsunami wave should be considered in the design process. As well, the potential for a tsunami to cause localized scour of the beachface and nearshore seabed should be assessed. During a tsunami, considerable reshaping of the shoreline can occur, leaving the coastal facilities more exposed to future wave and current forces.

Other Types of Coastal Hazards

Although this assessment has specifically addressed tsunami hazard at the project site, we note that it is possible that other natural hazards may pose a greater threat than a tsunami. In particular, a severe tropical cyclone directly striking the site could produce a large storm surge due to the combined effects of both the reduced atmospheric pressure at the centre of the tropical cyclone and the induced stress of the high wind speeds on the water's surface. This elevated water level, in association with the large waves created by the tropical cyclone winds, may be more damaging and have a significantly greater probability of occurrence than a tsunami.

In addition, the sustained conditions occurring in a tropical cyclone can result in considerable sediment movement in coastal regions. The evolution of the beach face can significantly affect the loads and design conditions for any structure near the shoreline or passing beneath the shoreline (e.g. the pipeline).

It is possible that the provision of protection against tropical cyclone events may also result in a reasonable level of tsunami protection.

Protection of the Project Site

Should SNC-Lavalin wish to consider the protection of the processing plant site against tsunami or storm surge inundation, two possible approaches include:

- Creation of a berm around the project site. The simplest, and most common, method of protection would be the construction of an earth berm around the project site to a specified design elevation. This berm would prevent the inflow of water to the project site. The berm would need to be armoured with stone on the outer face to limit erosion during a design event.
- Drainage design. An alternative is to design the processing plant facilities to accommodate the influx of the water associated with a tsunami or surge. This

would include prevention of the submergence of electrical and mechanical components, and appropriate design of drainage pathways.

Protection of the coastal facilities (jetty and receiving station) is more complex, and may require the incorporation of scour protection. An important consideration with respect to the jetty is the potential for hydrostatic uplift on the under-surface of the structure, which can generate large vertical forces on pile supports.

Conclusions

The following conclusions were derived on the basis of this preliminary assessment for tsunami hazard:

- Tsunamis in the Indian Ocean are an infrequent event. In the past 125 years, there have only been four to six events of a magnitude sufficient to generate a measurable (greater than a few centimeters) tsunami wave along the eastern shoreline of Madagascar.
- Except for a very localized tsunami originating in Diego Garcia in 1983, all of the significant historical tsunamigenic events have occurred at a considerable distance from Madagascar, primarily originating along the Indonesia coastline. Tsunami waves disperse with distance, thus there is a limit to the magnitude of tsunami runup that can occur in Madagascar.
- It is probable that the December 26, 2004 Indian Ocean tsunami is the largest tsunami incident to the eastern shoreline of Madagascar to have occurred in recent history (greater than 125 years). This event was estimated to have caused a runup in the order of 1 to 2 metres at the coastline adjacent to the proposed project site, based on empirical calculations.
- It may be possible for a larger tsunami runup, in the order of 3 to 4 metres, to occur at the project site in the future, if an earthquake of similar or greater intensity to the 2004 event were to originate at a location further south along the Indonesian coastline, resulting in more direct propagation of the tsunami wave towards Madagascar.
- The proposed shoreline facilities, consisting of a ship berth and a products receiving station, may be subject to tsunami inundation. The design of these facilities should consider the water level impacts, high current velocities and possible shoreline re-shaping that might occur in a tsunami.

- Other types of coastal hazards may pose a threat to the proposed project. In particular, this area is subject to the passage of tropical cyclones. A severe tropical cyclone directly striking in the vicinity of the project site can potentially generate large storm surge and wave conditions at the coastline.

Recommendations for Future Actions

The following recommendations for possible future actions were derived on the basis of this study:

- Specific details of the tsunami runup for the December 26, 2004 event in the vicinity of the proposed project site should be obtained. Ideally, these data should be derived from nearby tidal records or from local observations of residents. Given the relatively low level of runup estimated for the site, it is unlikely that direct evidence (e.g. shoreline debris) remains.
- More detailed numerical modeling of tsunami runup and inundation could be performed to assess the potential impacts of a tsunami of similar or increased severity to the December 26, 2004 event. We note that our estimates of runup are based on simplistic calculations by means of empirical equations, assuming planar nearshore slopes. A numerical model can properly account for the spatial variations in the site bathymetry and topography. Such a model can provide an indication of tsunami inundation levels and current velocities.
- Comprehensive analyses of tropical cyclone surge and wave conditions should be carried out in association with future design activities at this site. A severe tropical cyclone may generate significant increases in water level at the coastline due to atmospheric pressure and wind stress effects. As well, very large wave conditions can be created, which can, in turn, cause large-scale re-shaping of the beach face. These analyses should include the statistical evaluation of the probability of occurrence of tropical cyclones, and numerical modeling of tropical cyclone-induced surge, wave and sediment transport processes.

Mr. Michel Weiss

February 14, 2005

Page 10

Baird

We thank you for the opportunity to carry out this study, and look forward to discussing the results with you.

Yours truly,

W.F. Baird & Associates Coastal Engineers Ltd.

A handwritten signature in black ink, appearing to read 'R. Douglas Scott', written in a cursive style.

R. Douglas Scott, Ph.D., P.Eng.

Principal

File No. 10923

Mr. Michel Weiss

February 14, 2005

Page 11

Baird

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Murty, T.S. and Rafiq, M. (1991). A Tentative List of Tsunamis in the Marginal Seas of North Indian Ocean. *Natural Hazards* (1991) vol.4, no.1, p.81-3.

Simkin, T., Unger, J.D., Tilling R.I., Vogt P.R., and Spall H., 1994. This Dynamic Planet: *World Map of Volcanoes, Earthquakes, Impact Craters, and Plate Tectonics*

Synolakis, C.E. (1987). "The runup of solitary waves," *Journal of Fluid Mechanics*, Vol 185, 523-545.

NGDC Tsunami Event Database. Online source located at:
http://www.ngdc.noaa.gov/seg/hazard/tsevsrch_idb.shtml

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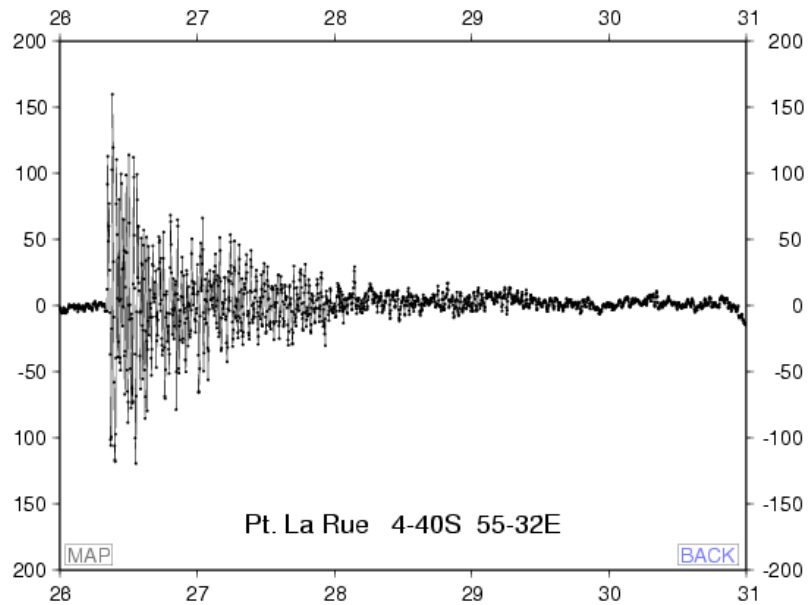


Figure 1 Water Level Residual Record at Pt. La Rue, Seychelles

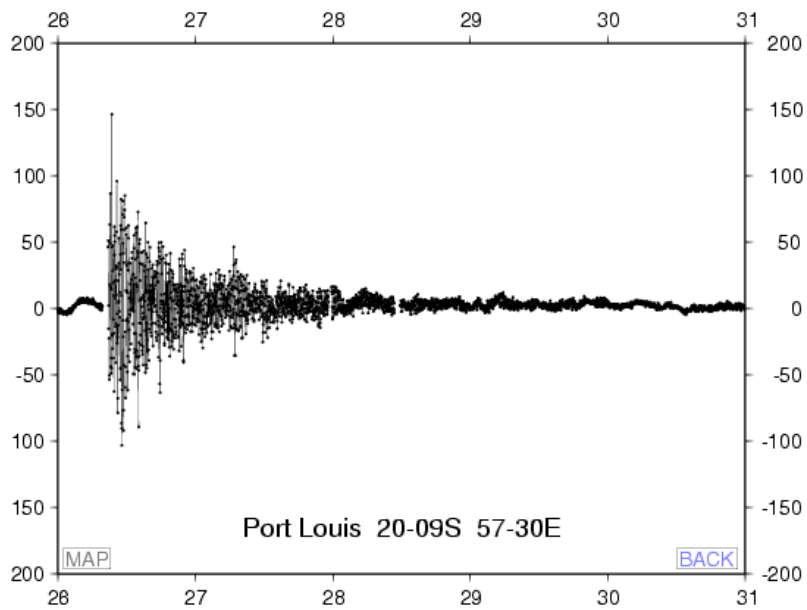


Figure 2 Water Level Residual Record at Port Louis, Mauritius

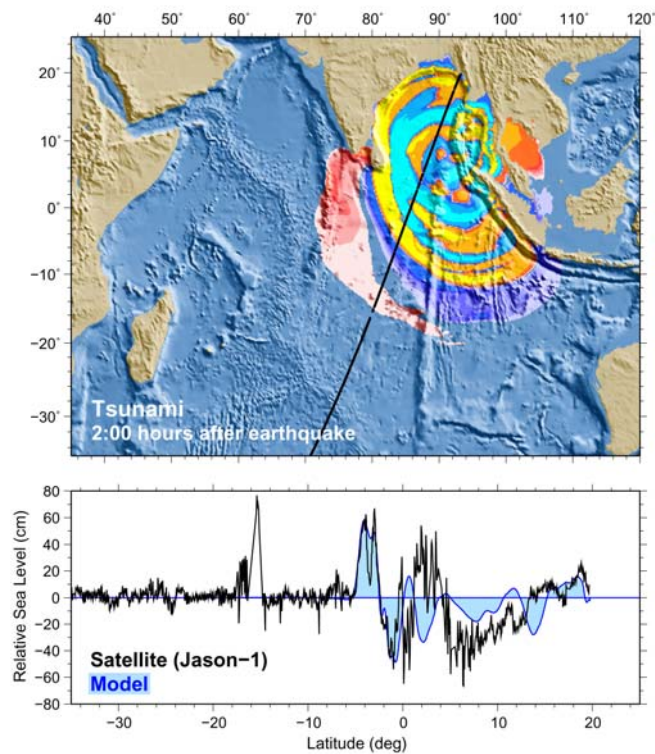


Figure 3 Comparison of the NOAA Tsunami Model and "Jason" Satellite
Source: NOAA News Online, Story 2365

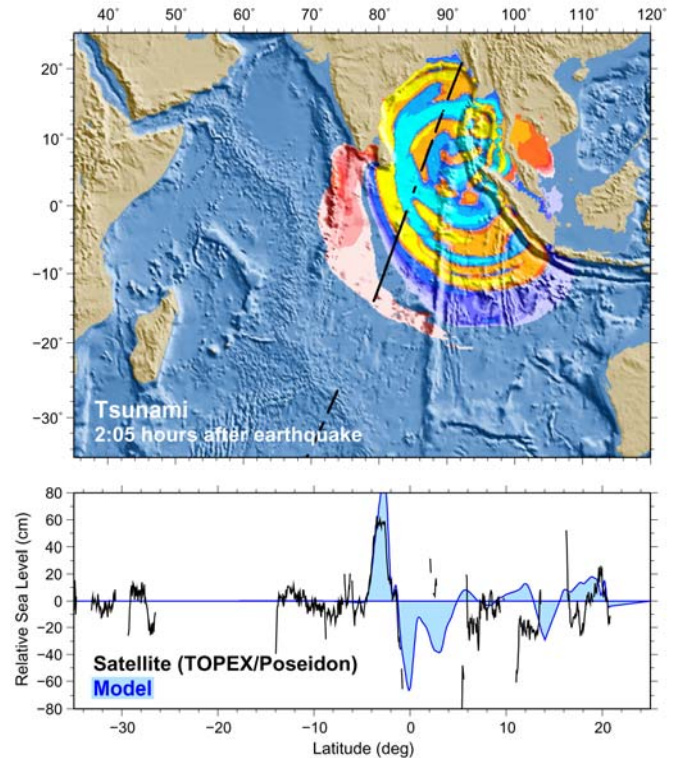


Figure 4 Comparison of the NOAA Tsunami Model and "TOPEX" Satellite
Source: NOAA News Online, Story 2365

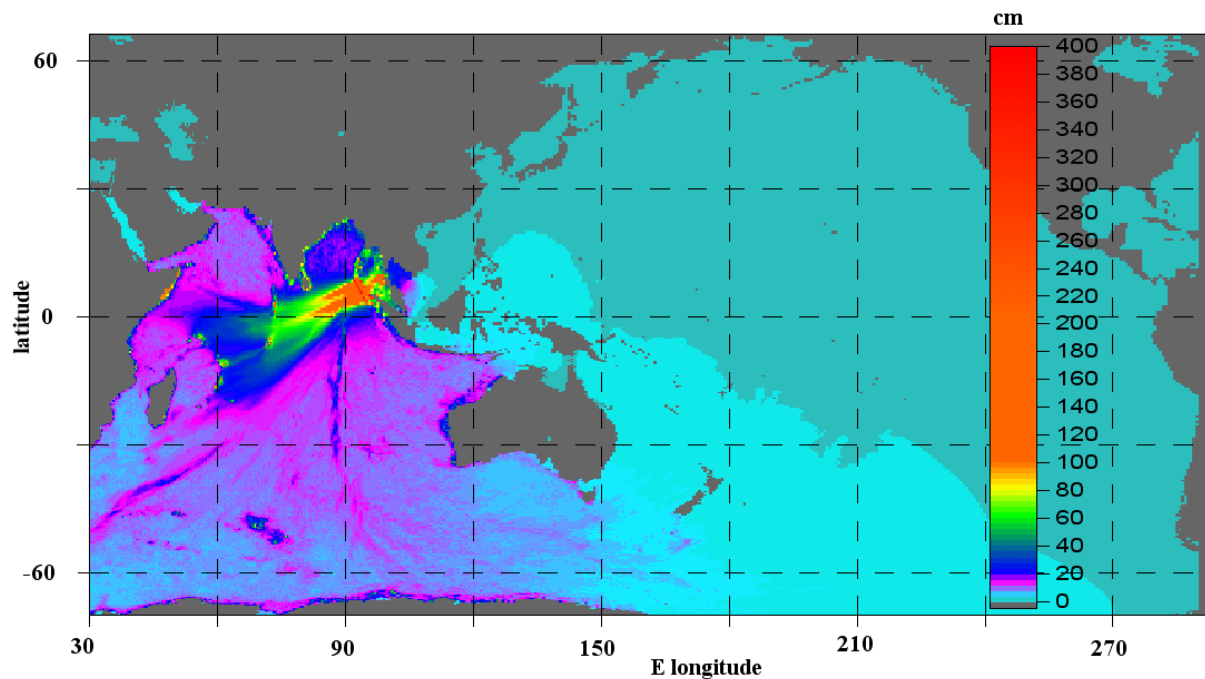


Figure 5 Maximum Wave Height from the NOAA Tsunami Model
[Source: West Coast Alaska Tsunami Warning Center]
[<http://wcawtc.gov/IndianOSite/heights20.gif>]

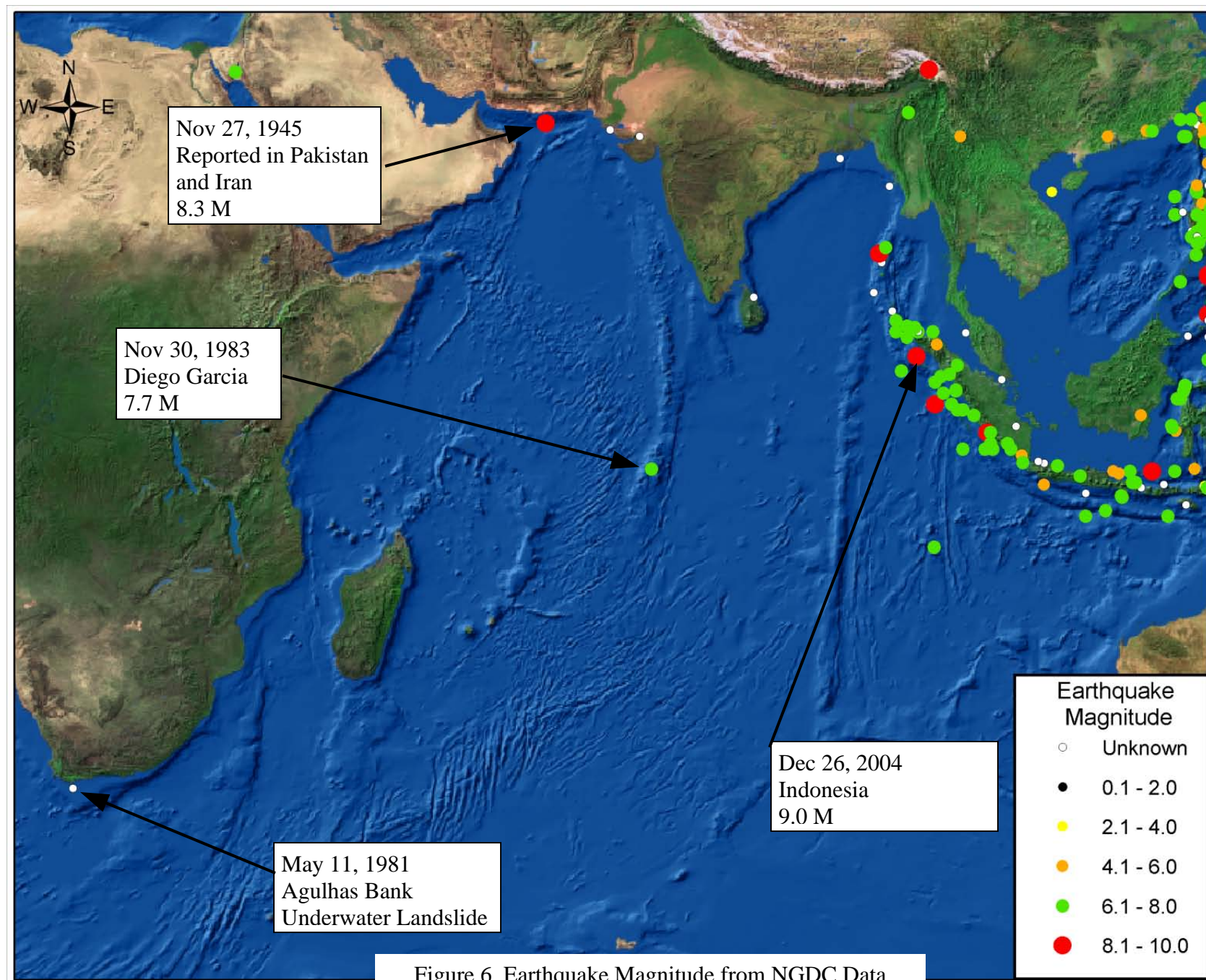


Figure 6 Earthquake Magnitude from NGDC Data
Data Source: NGDC Tsunami Event Database

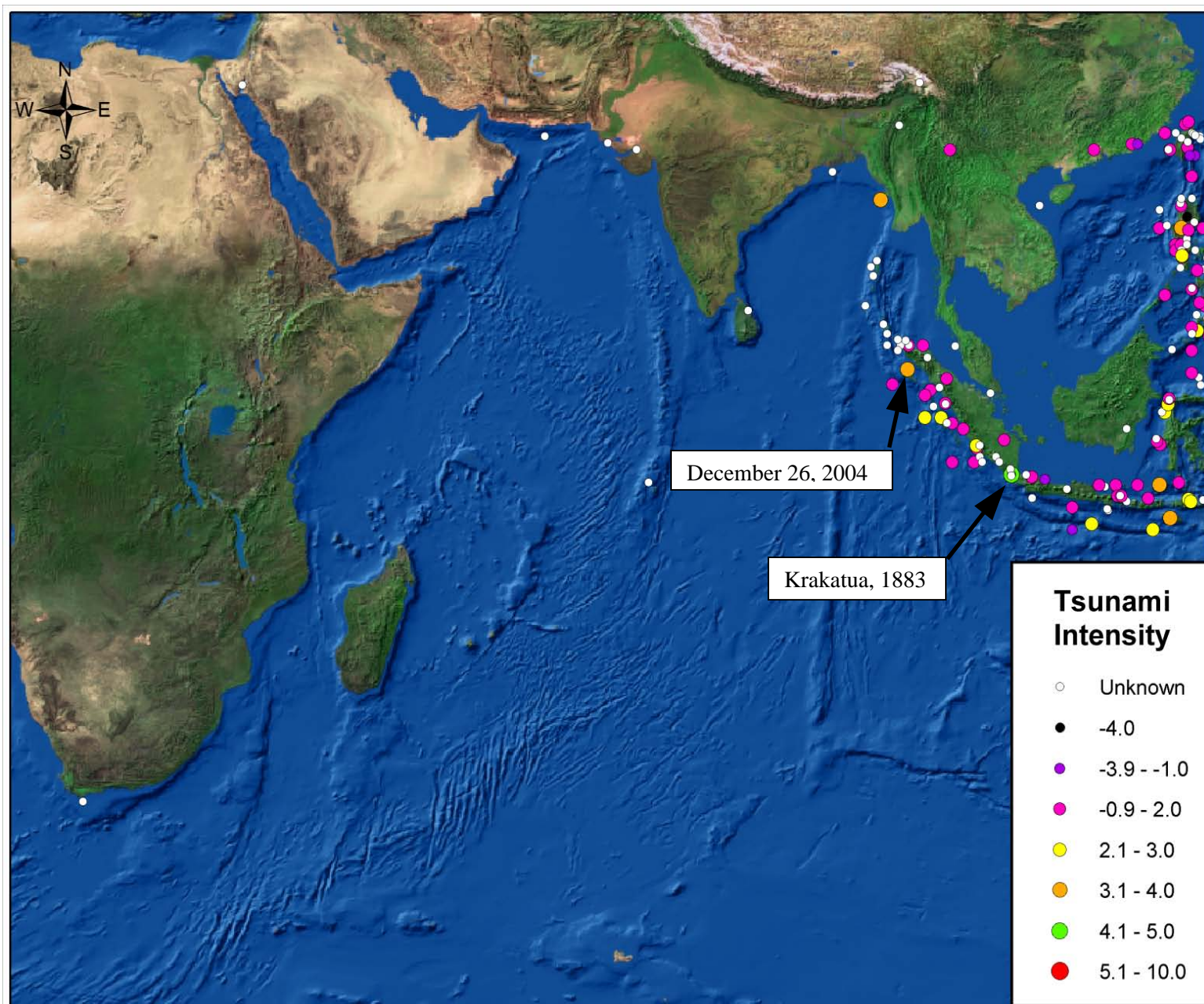


Figure 7 Tsunami Intensity from NGDC Data
Data Source: NGDC Tsunami Event Database

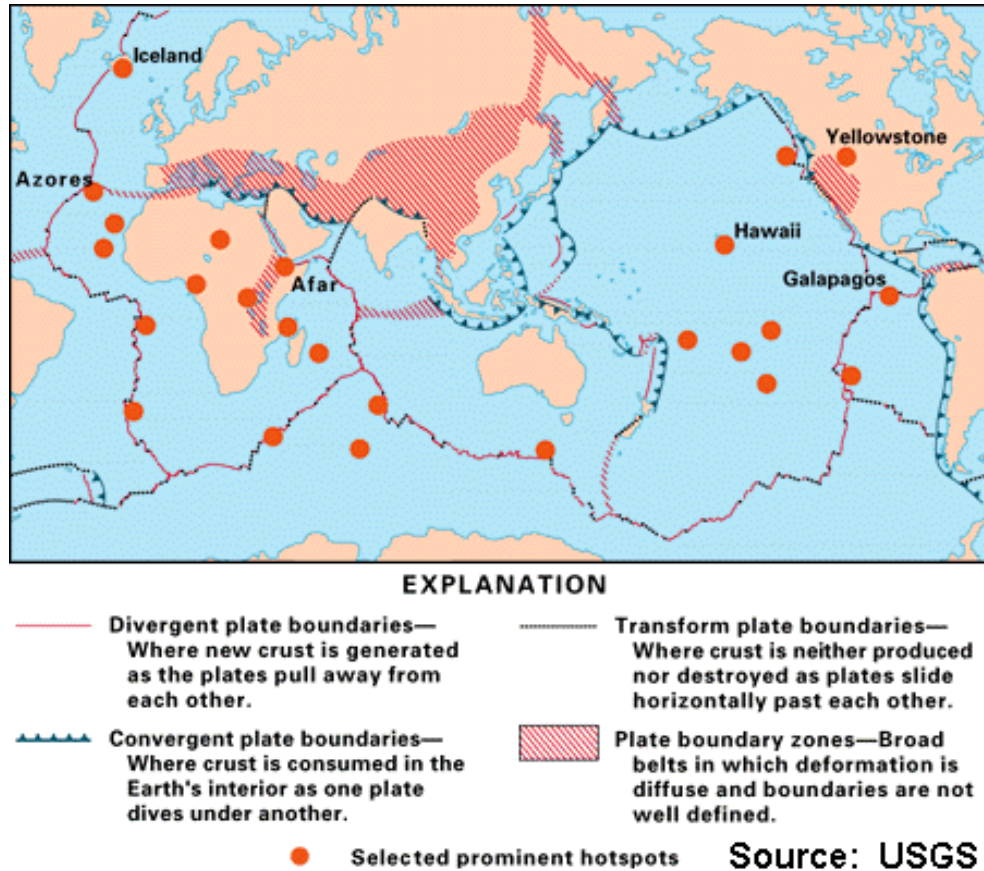


Figure 8 Tectonic Plates of the World
[Source: "This Dynamic Planet" Simkin et al, 1994]

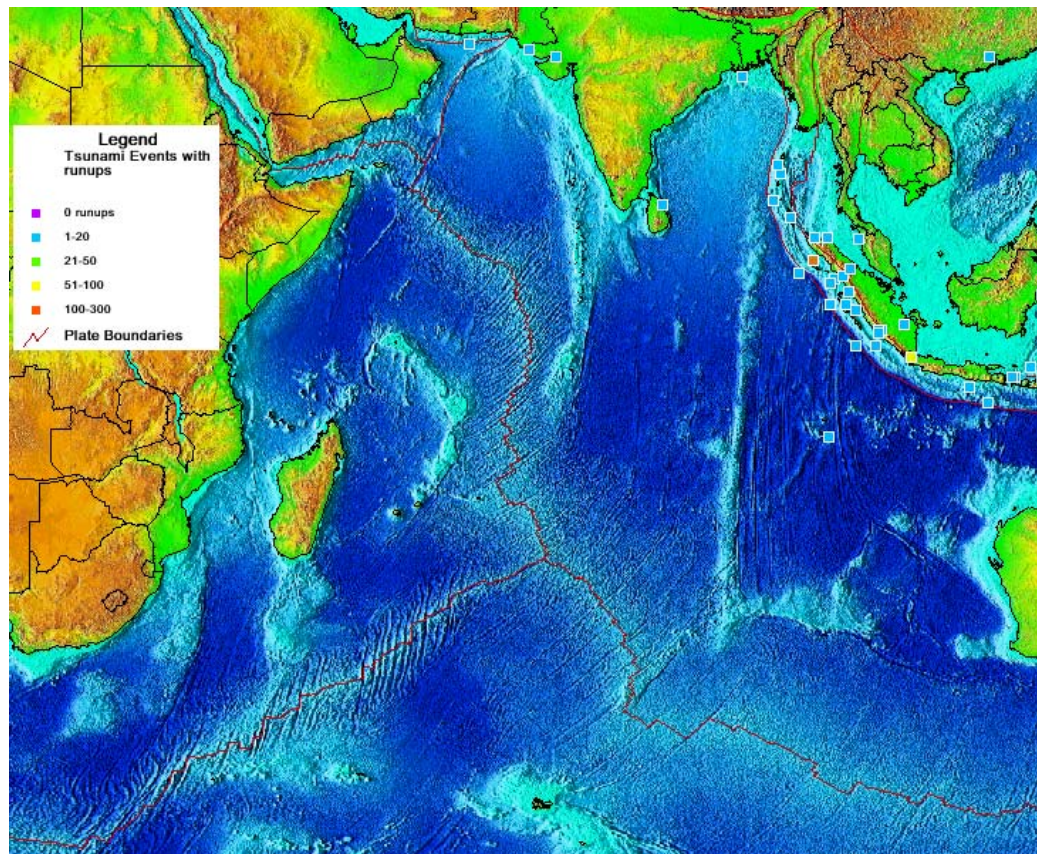


Figure 9 – Tsunami Events and Plate Boundaries
[Source: NGDC Tsunami Event ArcIMS Server]

VOLUME I

APPENDIX 7.1

ATTACHMENT 1

**AMBATOVY & ANALAMAY MINING PROJECT – MADAGASCAR
UPDATE OF NUMERICAL MODEL
MAY 2005**

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Ambatovy & Analamay Mining Project - Madagascar

Update of Numerical Model May 2005



GCS Report 04.01-110/2

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Appendix A: Aquifer Test Data.
Appendix B: Unsaturated Seepage Modelling Report.

1. Introduction and Terms of Reference.

GCS (Pty) Ltd. was contracted by Dynatec to perform a hydrogeological investigation for the Ambatovy & Analamay mining project in Madagascar. The investigation commenced in June 2004. The aim of the investigation was to characterise the hydrogeological environment and to predict the potential influence of the proposed mining activities on the groundwater regime.

The initial study was completed in December 2004 (Refer to GCS Report 04.01-110, December 2004). The investigation was performed during the dry season when most of the rainwater that recharged into the overlying ferricrete layer had already exited from the groundwater system in the form of spring flow. Only a small percentage of the infiltrating water recharges the underlying ferralite, transition zone, and base rock through vertical seepage. Due to this, little water was intercepted in the monitoring boreholes at the end of the dry season when the aquifer tests were performed and very little useable data could be obtained.

Therefore, it was decided to perform additional aquifer tests during the rainy season (April 2005) when it was expected that there would be more groundwater present in the aquifers due to recent recharge from rainwater.

The results of the additional hydrogeological study are discussed in this report.

2. Scope of Work.

The scope of work for the additional hydrogeological study included:

- Short hydrocensus to measure the groundwater levels in all the boreholes.
- Aquifer testing on the test pumping boreholes.
- Data analysis.
- Update of the numerical model incorporating the new data.
- Reporting.

3. Methodology.

3.1. Hydrocensus.

During the hydrocensus the groundwater levels in all the accessible boreholes were measured. Other relevant data such as coordinate position, topographical height and collar height were also correlated against the available data.

The results of the hydrocensus conducted in April 2005 are summarised in Table 3.1.1, together with the data recorded in August 2004 and March 2005. The aquifer that each borehole is considered to monitor is also indicated. It should be noted that the groundwater level in each borehole could be a combination of the piezometric pressure of more than one aquifer, and the indicated aquifers are an estimate only. The positions of the boreholes are shown in Figure 3.1.1.

The data indicates that the groundwater level increased between August 2004 (end of dry season) to March 2005 (end of rainy season). During the period March 2005 to April 2005 (beginning of dry season) the groundwater level generally decreased. However, in April 2005 the groundwater level is still above that of August 2004. The increase in groundwater level between August 2004 and March 2005 in the aquifers ranges between 0.56 and 14.28m.

Table 3.1.1: Hydrocensus Results.

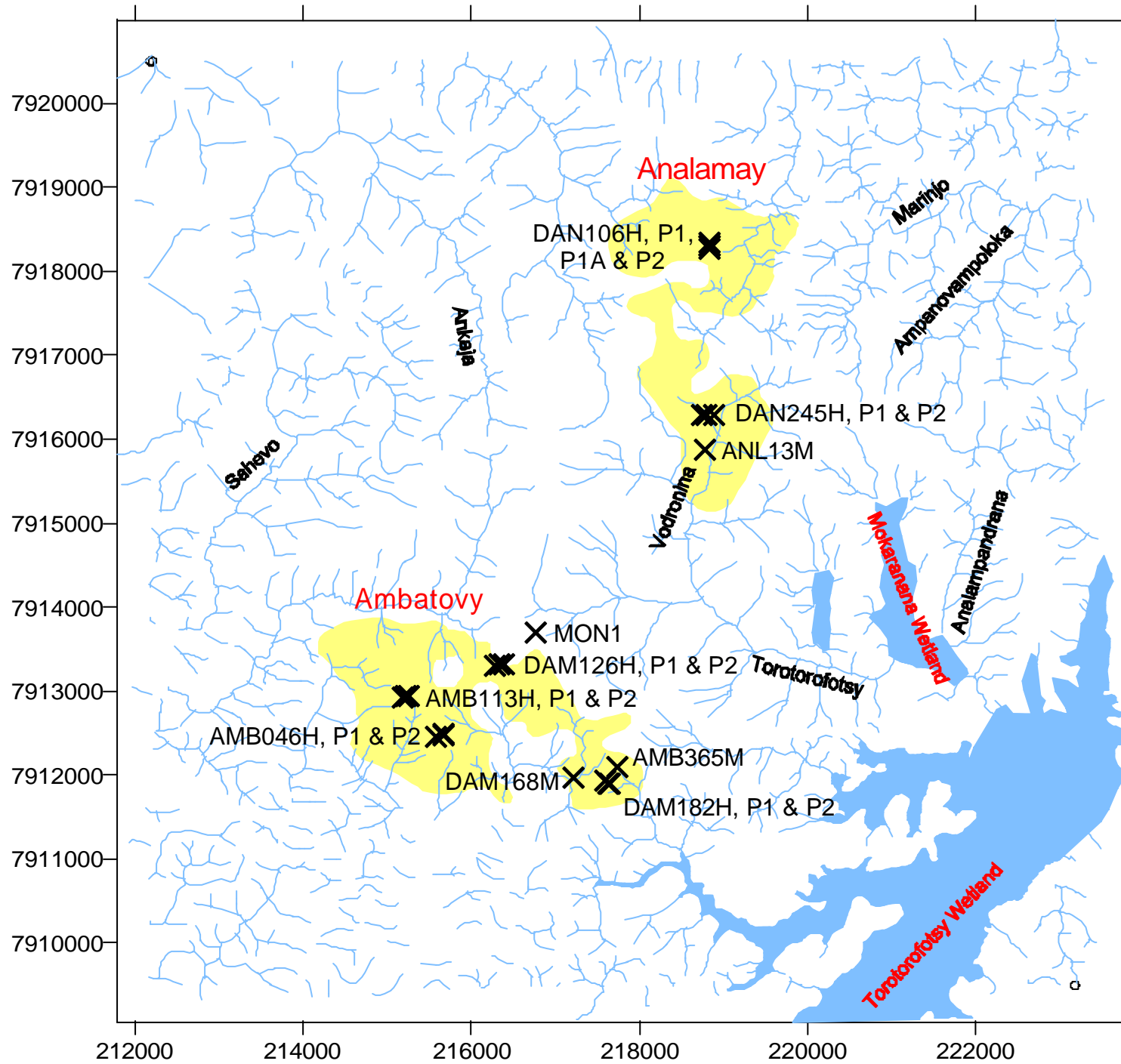
Borehole	UTM-X	UTM-Y	Topography (mamsl)	Depth (mbgl)	Stick-up (magl)	Water Level August 2004 (mbgl)	Water Level March 2005 (mbgl)	Water Level April 2005 (mbgl)	Aquifer
DAN106H	218834	7918263	1092.76	39.00	0.21	8.35	6.90	7.26	Ferricrete
DAN106P1	218832	7918311	1091.17	23.80	0.29	6.20	3.80	4.40	Ferricrete
DAN106P1A	218831	7918307	1091.17	34.25	0.30	8.92	5.57	6.30	Ferricrete
DAN106P2	218833	7918348	1092.22	27.25	0.33	ND	4.85	5.40	Ferricrete
DAN245H	218804	7916286	1039.06	46.25	0.25	22.20	21.37	21.45	Ferralite
DAN245P1	218753	7916296	1039.01	20.00	0.21	9.04	5.31	5.69	Ferricrete
DAN245P2	218886	7916294	1040.89	19.94	0.30	Dry	Dry	Dry	-
AMB046H	215668	7912483	1117.06	48.85	0.29	28.82	15.91	19.09	Ferralite
AMB046P1	215662	7912476	1122.39	40.60	0.23	28.15	24.02	22.64	Ferralite
AMB046P2	215574	7912455	1116.56	49.20	0.24	27.25	23.85	25.55	Ferralite
DAM182H	217602	7911924	1056.72	55.00	0.28	38.75	27.93	Blocked	Ferralite
DAM182P1	217628	7911899	1058.92	46.42	0.28	46.20	45.64	45.93	Saprolite
DAM182P2	217655	7911892	1058.00	46.47	0.25	45.80	44.46	45.46	Saprolite
DAM126H	216276	7913301	1103.39	83.20	0.06	51.66	47.10	47.33	Saprolite
DAM126P1	216336	7913313	1104.28	68.10	0.26	22.99	21.68	22.28	Ferralite
DAM126P2	216390	7913322	1105.03	63.85	0.25	10.05	6.29	6.37	Ferricrete
AMB113H (AMB129H)	215179	7912919	1131.62	73.87	0.41	27.00	14.62	17.27	Ferralite
AMB113P1 (AMB129P1)	215212	7912932	1130.51	31.40	0.05	20.70	6.42	9.73	Ferricrete
AMB113P2 (AMB129P2)	215253	7912943	1132.17	34.45	0.21	22.10	11.96	14.60	Ferralite
AMB365M	217730	7912103	1044.50	55.70	0.10	ND	54.59	54.73	Saprolite
DAM168M	217212	7911962	998.50	19.10	0.13	ND	12.62	12.91	Ferralite
MON1	216769	7913700	1083.22	48.20	0.22	ND	18.58	19.61	Ferralite
ANL13M	218785	7915873	1024.14	22.00	0.12	ND	21.86	22.00	Ferralite




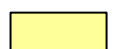
Mamsl = meters above mean sea level

Mbgl = meters below ground level

Magl = meters above ground level

ND = No data




-  Borehole Position
-  River
-  Surface Water Body
-  Ore Body Area

CLIENT:
Dynatec

PROJECT:
Ambatovy & Analamay Nickel Mine
Madagascar
GCS Project No: 04.02.110

DRAWING TITLE:

Hydrocensus Borehole
Positions

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DRAWN	M. Prinsloo	May 2005
DESIGNED		
CHECKED / REVIEW		
SCALE	As Shown	
DRAWING No.	3.1.1	REVISION

The data indicate a rapid decrease in groundwater level from March to April. This confirms that a large percentage of the water recharged to the aquifers exits the groundwater system in the form of seepage into the rivers as baseflow contribution, and very little migrates downwards to recharge the deeper aquifers.

As stated above, it is considered that each borehole mainly reflects the groundwater level of a specific aquifer, and not a combination of all the aquifers. This can be illustrated when comparing the groundwater levels in boreholes DAM126H, DAM126P1 and DAM126P2. The boreholes are drilled within 50m of each other. However, the water level in borehole DAM126H is 47.33mbgl, DAM126P1 is 22.28mbgl and DAM126P2 is 6.37mbgl. Figure 3.1.2 shows the groundwater levels as observed during the hydrocensus plotted against the topography, and the respective trend lines.

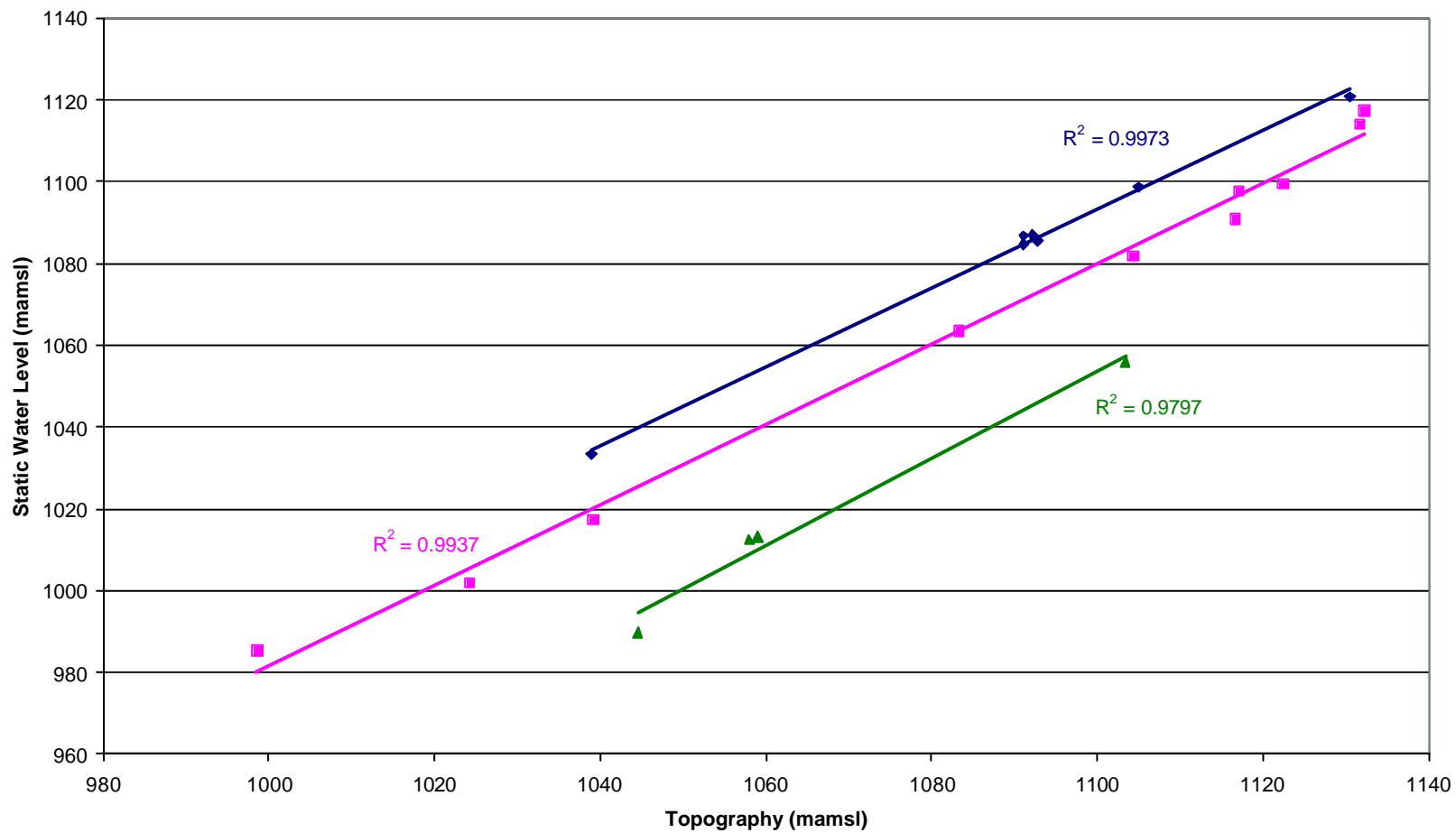
The figure shows distinctive trends for the respective aquifers. However, when comparing the topographic versus static water level data a linear fit is achieved for each of the aquifers. This indicates that there are no external factors currently influencing the groundwater levels. This could change once the mining activities start and dewatering of the aquifers occurs.

A general groundwater contour map of the study area has been compiled, and is shown in Figure 3.1.3. The figure shows that groundwater flow direction in the area of interest varies due to the mountainous nature of the site.

The Ambatovy West pit is situated on a topographic high (groundwater flow divide) and groundwater will migrate away from the site in a south-south westerly and a south easterly direction. Groundwater migrating in the south easterly direction could eventually contribute to the Torotorofotsy wetland area.

The Analamay mine pit is also situated on a groundwater flow divide. It is expected that groundwater in the vicinity of the proposed Analamay south pit area will eventually reach the Torotorofotsy wetland area.

The average groundwater flow gradient is calculated as approximately 0.08 (1:12).



◆ Ferricrete ■ Laterite ▲ Saprolite — Linear (Ferricrete) — Linear (Laterite) — Linear (Saprolite)

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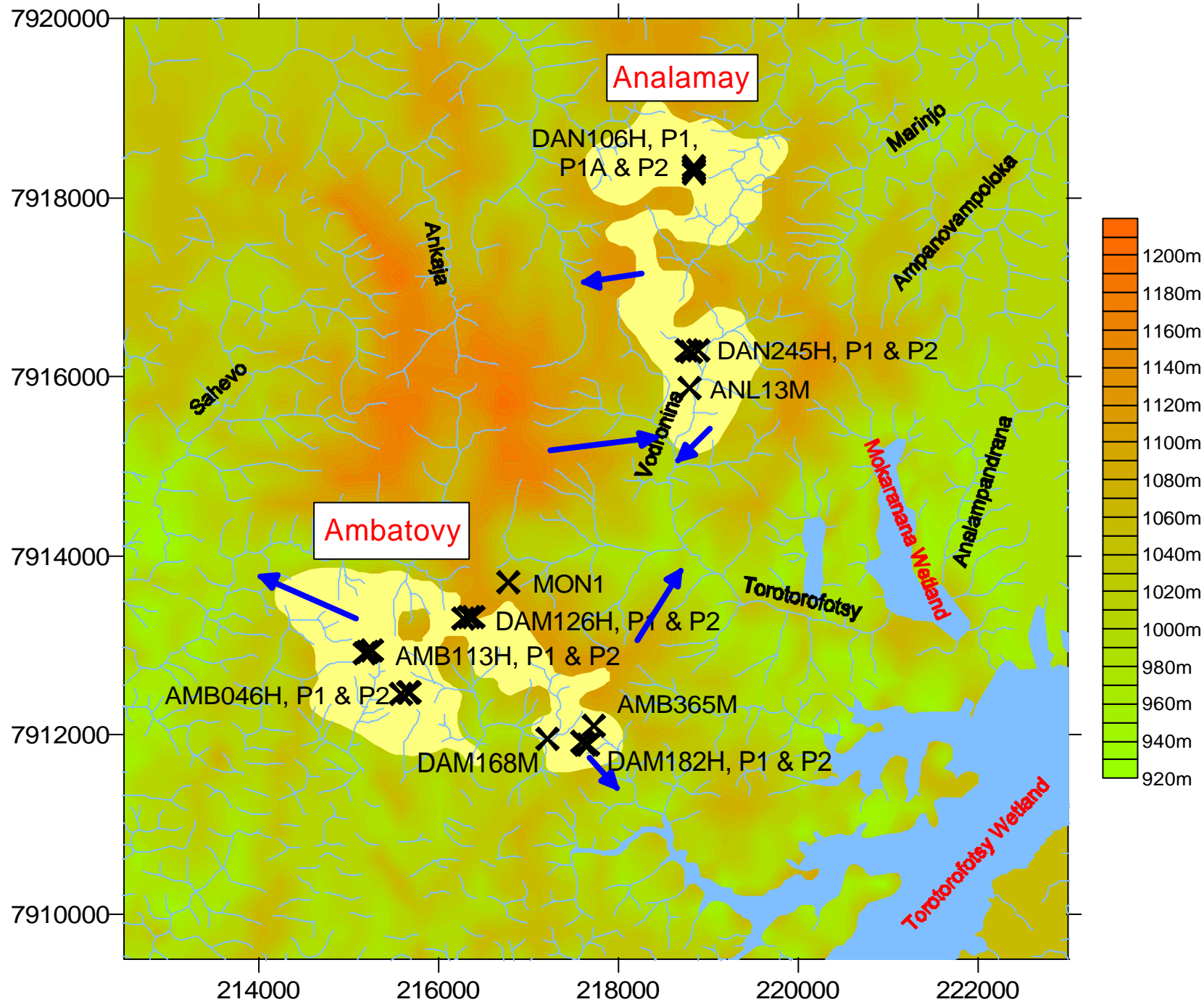
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Ambatovy & Analamay Nickel Mine
Madagascar
GCS Project No: 04.02.110






DRAWING TITLE:

Static Water Level vs. Topography
(Individual Aquifers)

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-  Groundwater Flow Direction
-  Borehole Position
-  River
-  Surface Water Body
-  Ore Body Area

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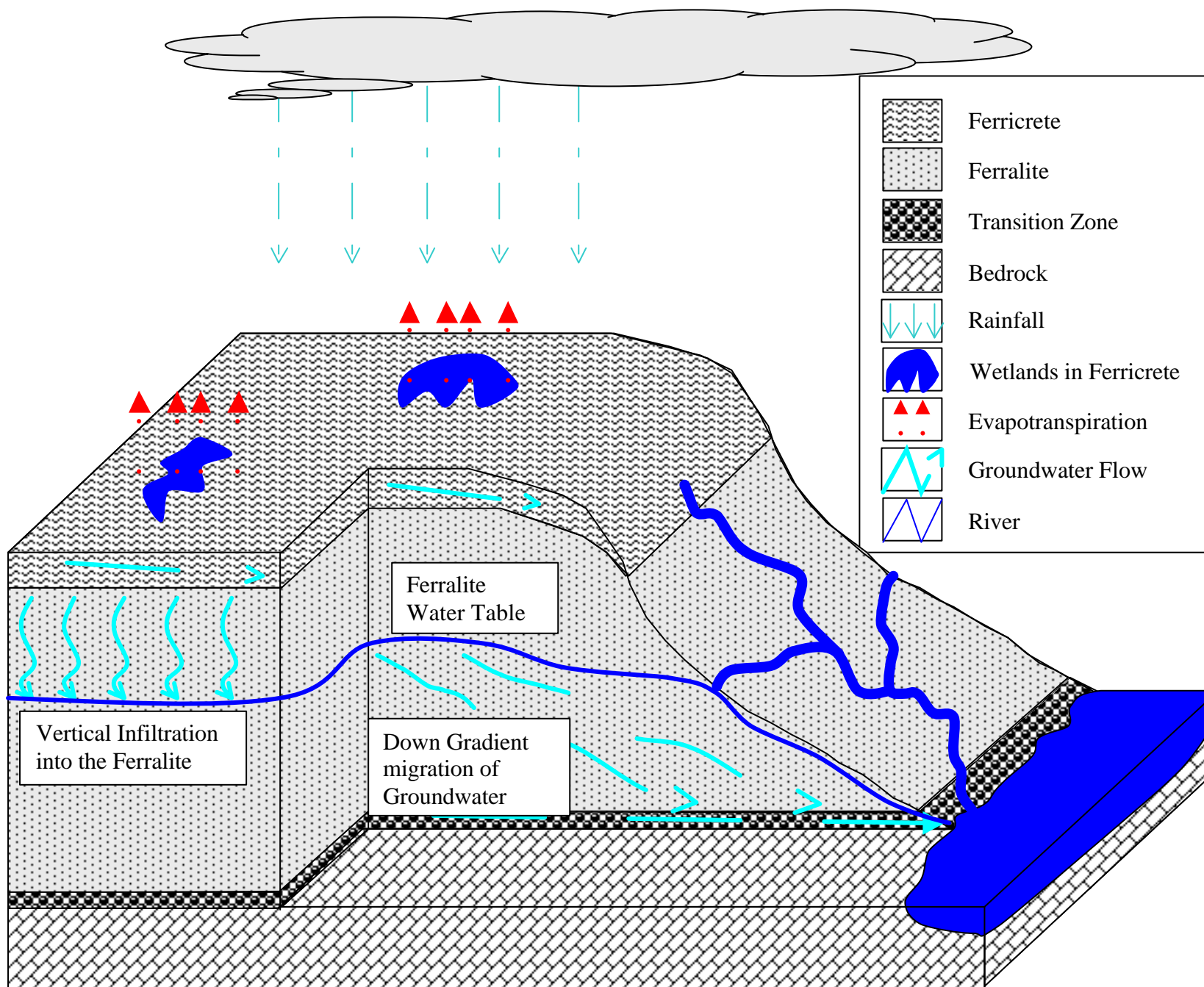
PROJECT:
Ambatovy & Analamay Nickel Mine
Madagascar
GCS Project No: 04.02.110

DRAWING TITLE:
Groundwater Level Contours



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DRAWING No.	3.1.3	REVISION



CLIENT:
Dynatec

PROJECT:
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Madagascar
GCS Project No: 04.02.110

DRAWING TITLE:
Conceptual Groundwater Model



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SCALE	As Shown	
DRAWING No.	3.1.4	REVISION

3.2. Aquifer Testing.

Aquifer test pumping was performed on boreholes AMB046, AMB113, DAM126, and DAN245. The data obtained during the tests are shown in Appendix A. The results of the aquifer test data analysis are summarised in Table 3.2.1. It is considered that the transmissivities calculated from the aquifer test data are a reflection of the transmissivity of the ferrallite, except in borehole DAN245 where the transmissivity is influenced by the transition zone material (saprolite).

Table 3.2.1: Aquifer Test Results.

Borehole	Transmissivity (m ² /day)			Storativity
	Theis	Cooper-Jacob	Theis-Jacob (Recovery)	
DAN245	52	54	20	ND
AMB113	0.27	0.42	0.34	ND
AMB046	0.37	0.27	0.17	ND
DAM126	0.19	0.27	0.09	ND
AMB113 P1	3.21	8.39	ND	0.000252

ND = No data

Generally, more weight is given to the transmissivities calculated from the recovery phase data due to the absence of the turbulence caused in the borehole due to the pumping action.

Table 3.2.1 indicates that the transmissivity of the aquifers calculated based on the recovery phase data range between 0.09 and 0.34m²/day for boreholes AMB046, AMB113, and DAM126. The transmissivity calculated for borehole DAN245 is 20m²/day.

As stated above, it is considered that the transmissivities in boreholes AMB046, AMB113, and DAM126 reflect the aquifer characteristics of the ferrallite. Borehole DAN245 is the only borehole where significant saprolite (transition zone) was encountered during the drilling program of 2004. Due to the physical characteristics of the saprolite (highly weathered and fractured parent rock which occurs horizontally or as boulders commingled with ferrallite), it is considered that the transmissivity of this layer can be at least one order of magnitude larger than that of the ferrallite. The difference in transmissivity between the saprolite (transition zone) and ferrallite was also noted during the Golder Associates investigation (1999).

Storativity values calculated on groundwater level reaction data in the borehole that is being pumped are often inaccurate. It is normally recommended that the groundwater level in a borehole located close by (generally less than 50m) be recorded during the aquifer testing. The storativity of the aquifer can then be calculated based on the groundwater level reaction data in this observation borehole.

During the aquifer testing at Ambatovy and Analamay the groundwater level reaction in the close by piezometer boreholes was recorded. Groundwater level reaction data that was particularly valuable was that recorded in borehole AMB113 P1. This data is also shown in Appendix A.

Based on the data recorded in borehole AMB113 P1, the storativity of the aquifer is calculated as 0.000252.

3.3. Numerical Model Update.

The numerical model was updated based on the information obtained during the 2005 field investigation, as well as new information on the collection and clarification ponds' localities and sizes. Changes include:

- Differentiation between groundwater levels for various aquifers: During the 2004 field investigation very few groundwater levels were recorded due to the fact that it was at the end of the dry season and the boreholes were dry. Reference was made to data obtained during the Golder Associates investigation (1999). It was assumed that the groundwater levels represent a combination of all the aquifers in the area. During the 2005 field investigation groundwater levels were measured in the monitoring boreholes. The groundwater levels show differentiation between the individual aquifers.
- Differentiation in aquifer parameters between the Ambatovy and Analamay areas for the ferricrete and ferralite.
- Inclusion of the water collection and clarification ponds: At the time when the 2004 simulations were performed no final information on the localities, sizes and depths of the water collection and clarification ponds were available. Therefore these ponds could not be included. New data is currently available and the ponds were included in the simulations. Unsaturated seepage modelling was performed to determine the seepage rate from the ponds to the underlying aquifer (Refer Appendix B)
- Incorporating transmissivities obtained from the aquifer tests: The transmissivities obtained from the aquifer tests were incorporated into the numerical model. This involved a change in transmissivity of the ferralite (layer 2) from 4.56 to 0.1.

Calibrating the model (matching calculated groundwater levels to observed groundwater levels) proved to be difficult. During the calibration process the aquifer parameters such as transmissivity and recharge percentage was varied within realistic values in order to obtain the best possible correlation between the calculated and observed groundwater levels.

During the calibration process it became clear that it was difficult to correlate the calculated and observed groundwater levels occurring in the ferralite. A better fit could be obtained by specifying the transmissivity of this lithology at an extremely low value (below $0.01\text{m}^2/\text{day}$). However, this is considered to be unrealistic, and therefore the transmissivity was specified at a minimum of 0.01. This falls within the same order of magnitude as the lowest transmissivity obtained from the aquifer tests (0.09), but is considered to be the lowest value that can realistically be designated to the layer.

The calibrated values are summarised in Table 3.3.1.

Table 3.3.1: Model Calibrated Values.

Parameter	Layer	Area	Unit	Calibrated Value
Transmissivity	Ferricrete	Ambatovy Area	m^2/day	0.70
		Analamay Area	m^2/day	2.00
		Torotorofotsy	m^2/day	1.04
	Ferralite	Ambatovy Area	m^2/day	0.01
		Analamay Area	m^2/day	1.00
		Torotorofotsy	m^2/day	0.19
	Transition zone (saprolite)	Ambatovy Area	m^2/day	0.50
		Analamay Area	m^2/day	0.50
		Torotorofotsy	m^2/day	0.29
	Bedrock	Ambatovy Area	m^2/day	1.00
		Analamay Area	m^2/day	1.00
		Torotorofotsy	m^2/day	0.35
Recharge	Applied to top grid layer	Mine Area	% of annual rainfall	7%
		Torotorofotsy	% of annual rainfall	3%

The numerical model was used to predict the influence of the mining activities on the groundwater environment. During this process the mine plan as supplied by the client in 2004 was applied. Reportedly, the mine plan has not changed.

Results from the numerical modelling include groundwater inflow rates into the mine workings, drawdown cone extents and depths, and expected groundwater levels.

Influence on the Groundwater Environment in the Vicinity of the Mining Activities.

The expected groundwater inflow volumes are listed in Table 3.3.2. The groundwater inflow volume ranges between approximately 5 and 25l/s (420 to 2 100m³/day). The inflow volume fluctuates with time depending on the position of the main mining area in relation to previously mined areas, size of the area, and depth below groundwater level.

The table indicates that the majority of the seepage will occur from the ferricrete layer. This is due to the fact that the ferricrete has a much higher transmissivity than the ferralite. No seepage volumes from the transition zone is shown, as it is not planned that the mine pit depth will extend into this layer.

Little to no seepage is expected from the ferralite during phases 2, 6, 10, 11, and 14. This can be explained by considering the recharge characteristics of the aquifer system and the mine layout.

Table 3.3.2: Mine Inflow Volumes.

Phase	Mine Pit Inflow Volume (m ³ /day)			Mine Pit Inflow Volume (l/s)		
	Ferricrete (Upper Aquifer)	Ferralite (Lower Aquifer)	Total	Ferricrete (Upper Aquifer)	Ferralite (Lower Aquifer)	Total
Phase 1	969.72	1.37	971.09	11.22	0.02	11.24
Phase 2	482.30	0.15	482.45	5.58	0.00	5.58
Phase 3	738.52	4.18	742.70	8.55	0.05	8.60
Phase 4	1839.84	229.13	2068.96	21.29	2.65	23.95
Phase 5	1186.96	51.93	1238.89	13.74	0.60	14.34
Phase 6	623.12	0.28	623.39	7.21	0.00	7.22
Phase 7	723.34	14.86	738.19	8.37	0.17	8.54
Phase 8	553.19	4.21	557.40	6.40	0.05	6.45
Phase 9	423.60	8.41	432.01	4.90	0.10	5.00
Phase 10	610.18	0.52	610.70	7.06	0.01	7.07
Phase 11	941.17	0.62	941.78	10.89	0.01	10.90
Phase 12	966.50	21.35	987.86	11.19	0.25	11.43
Phase 13	672.50	10.48	682.98	7.78	0.12	7.90
Phase 14	428.17	0.13	428.30	4.96	0.00	4.96

During the mining of Phase 1, the mining activities will dewater the upper and lower aquifers associated with the ferricrete and the ferralite surrounding the mine area. Due to the relatively high transmissivity of the ferricrete, the upper aquifer will be easily recharged by rainfall. Therefore groundwater will seep from the ferricrete into the areas mined during Phases 2, 6, and 11. The high transmissivity in the ferricrete is evident in Figures 3.3.1 and 3.3.2.

It is expected that due to a large volume of water being removed from storage in the aquifer during the mining of Phase 1, the volume of water seeping from the ferricrete into the mine pit during Phases 2, 6 and 11 will be less than that of Phase 1. The volume of water seeping into the mine pit during Phases 2, 6 and 11 will be largely dependent on the short-term recharge from rainfall.

Vertical recharge from the upper aquifer to the underlying ferrallite associated aquifer will be limited due to the high horizontal transmissivity of the ferricrete causing 50 to 60% of the water recharging to the ferricrete to migrate down gradient within the ferricrete. The groundwater migrating within the ferricrete will daylight as springs at small wetland areas and rivers.

Another factor contributing to low recharge of the underlying aquifer is the low vertical hydraulic conductivity of the ferrallite. This will limit the volume of water recharging the ferrallite aquifer from the overlying ferricrete.

Due to these two factors very little to no groundwater will have recharged to the dewatered lower ferrallite aquifer in the time period between mining the first phase in an area (e.g. Phase 1), and the mining of the second and third phases in the same area (e.g. Phases 2, 6 and 11).

The above processes also apply to the dewatering of the lower ferrallite aquifer around Phase 4 and the subsequent little to no water emanating from the aquifer during mining of Phases 10 and 14.

The extent and depth of the expected groundwater level drawdown cone with time is shown in Figures 3.3.3, 3.3.4, and 3.3.5 for years 10, 20 and 27 (end of mining) respectively. The shape of the drawdown cone is influenced by the steep topography and the presence of the perennial rivers.

The numerical model indicates that the cone of depression is expected to advance to a maximum distance of approximately 800m from the mining area. This is considerable less than the previous predictions of 1 to 1.5km. The reduction in extent is due to the decrease in aquifer transmissivity in the updated model. The reduction in aquifer transmissivity reduces the zone of influence.

It is expected that the groundwater level will decrease in the ferricrete layer, and that it will be temporarily dewatered in the vicinity of the mining activities between rainfall events and in the dry season. However, due to the high transmissivity the aquifer will quickly be recharged by rainfall, thereby providing an almost continuous inflow of seepage into the mining area.

The maximum drawdown is expected to be approximately 30m in the ferrallite aquifer.

Influence on the Torotorofotsy and Mokaranana Wetlands.

The mining activities will influence the volume of water that flows into the Torotorofotsy and Mokaranana wetland systems. Schematics indicating the interaction between the aquifers and the surface water systems are shown in Figures 3.3.6 and 3.3.7. The Mokaranana wetland system is interconnected to Torotorofotsy and any influence on Mokaranana will impact on Torotorofotsy as well.

It is expected that the baseflow contribution to the rivers will be impacted due to the mining activities. Some of the rivers impacted upon feed into Mokaranana or Torotorofotsy. The rivers feeding directly into Mokaranana or Torotorofotsy that are expected to be influenced are shown in Figure 3.3.8.

Taking into account the zone of influence of the drawdown cones, the rivers that will be influenced by the mining activities and the sub-catchment areas in which the rivers are situated, it is estimated that the baseflow contribution to the **affected rivers** that feed into Mokaranana and Torotorofotsy will be reduced by approximately 7%.

Based on this reduction in baseflow contribution and the actual measured river flow volumes in the Torotorofotsy (surface water area QESF-103) and Mokaranana Wetland (surface water area QESF-101) areas, the reduction in river inflow into the wetland systems **from the rivers that are affected** (see Figure 3.3.8) can be calculated.

Daily flow data are available for the time period 10 April 2004 to 23 February 2005. Data for both QESF-101 and QESF-103 indicate relatively low flow volumes for the time 10 April 2004 to 15 December 2004 when the flow volumes increase almost instantaneously (see Figure 3.3.9). This increase is presumably due to the effect of the rainy season.

The harmonic mean flow volume for the period 10 April to 14 December (dry season) is calculated as 0.012 and 0.13m³/sec for QESF-101 and QESF103 respectively.

The harmonic mean flow volume for the period 15 December 2004 to 23 February 2005 (rainy season) is calculated as 0.225 and 0.303m³/sec for QESF-101 and QESF103 respectively

Based on the above flow volumes the expected flow volumes during the mining phase can be calculated. It should be noted that the calculated volumes are considered to represent the worst-case scenario as the maximum influence of the mining on the base flow contribution is incorporated into the calculations and this will not be applicable for the whole of the mining phase. The results of these calculations are summarised in Table 3.3.3.

Table 3.3.3: Reduction in Affected River Inflow into the Wetland Systems due to Baseflow Contribution Decrease.

	Dry Season		Wet Season		Average	
	Observed (10 April 2004 to 14 December 2004)	Calculated with mining influence	Observed (15 December 2004 to 23 February 2005)	Calculated with mining influence	Observed (10 April 2004 to 23 February 2005)	Calculated with mining influence
Mokaranana Area (QESF-101)	0.012m ³ /sec	0.011m ³ /sec	0.225m ³ /sec	0.209m ³ /sec	0.015m ³ /sec	0.014m ³ /sec
Torotorofotsy Area (QESF-103)	0.13m ³ /sec	0.12m ³ /sec	0.303m ³ /sec	0.282m ³ /sec	0.155m ³ /sec	0.144m ³ /sec

It should be noted that the available data do not span a 12-month period and that the data for the wet season are not considered to be complete.

The reduction in water inflow volumes into the wetlands is expected to impact on the natural habitat. Due to reduced inflows the wetland area might be reduced and less water will be available for plant growth and animal life.

Due to a relatively higher portion of the water in the wetland system evaporating, the chemical character of the wetland systems could also be impacted upon.

Post-Mining Environment.

After mine closure the regional groundwater levels will recover due to the abstraction of groundwater from the opencast pits being stopped.

Due to the fact that the ferricrete which forms the upper aquifer is only 4m thick, and its high hydraulic conductivity it is expected that this aquifer will recover to the pre-mining state within 5 to 20 years depending on the locality.

The ferralite aquifer will recover slowly due to the low transmissivity of the material. It is expected that groundwater levels will recover to pre-mining conditions only between approximately 5 and 75 years after mine closure depending on the position.

The expected recovery of the groundwater level in boreholes DAN245P1 (Ferricrete) and AMP168M (Ferralite) is shown in Figure 3.3.10.

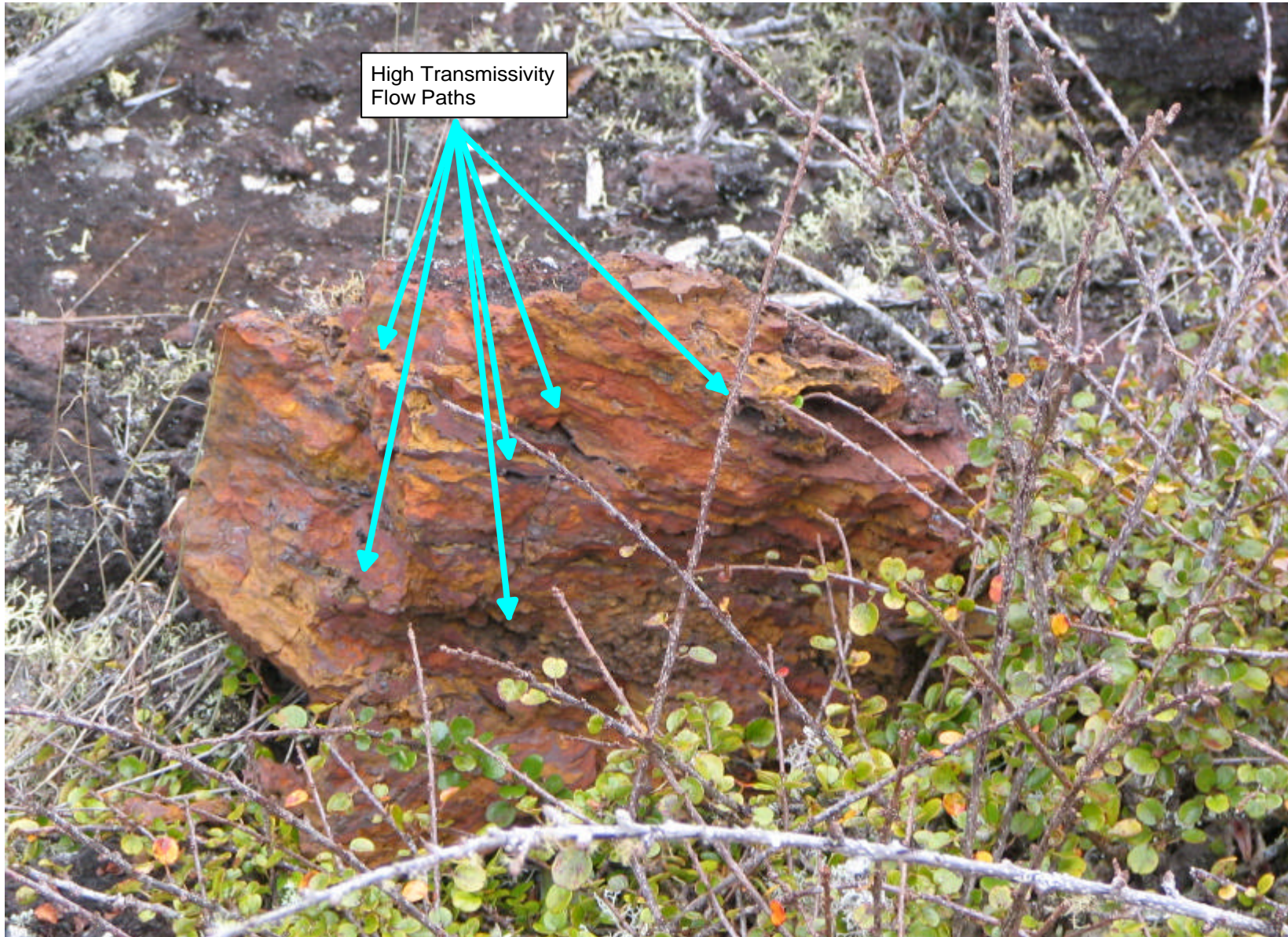
It is expected that decant from the mining areas will occur. Due to the steep topography and the mining areas falling within several sub-catchments, several decant positions are expected. Possible positions of decant are indicated on Figure 3.3.11. It is expected that decant will start to occur within 10 to 20 years of mine closure. The total volume of decant at each pit area is summarised below.

Table 3.3.4: Decant Volumes.

Pit Area	Decant Volume (l/s)	Decant Volume (m³/day)
Ambatovy	19	1 600
Analamay	23	2 000

Contamination Transport Modeling.

Due to the leached chemical nature of the mined material it is not expected that any acid mine drainage will form. Therefore, no contaminant transport modelling was performed.



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DRAWING TITLE:

High Transmissivity
nature of the
Ferricrete



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High Transmissivity Zone
in the Ferricrete



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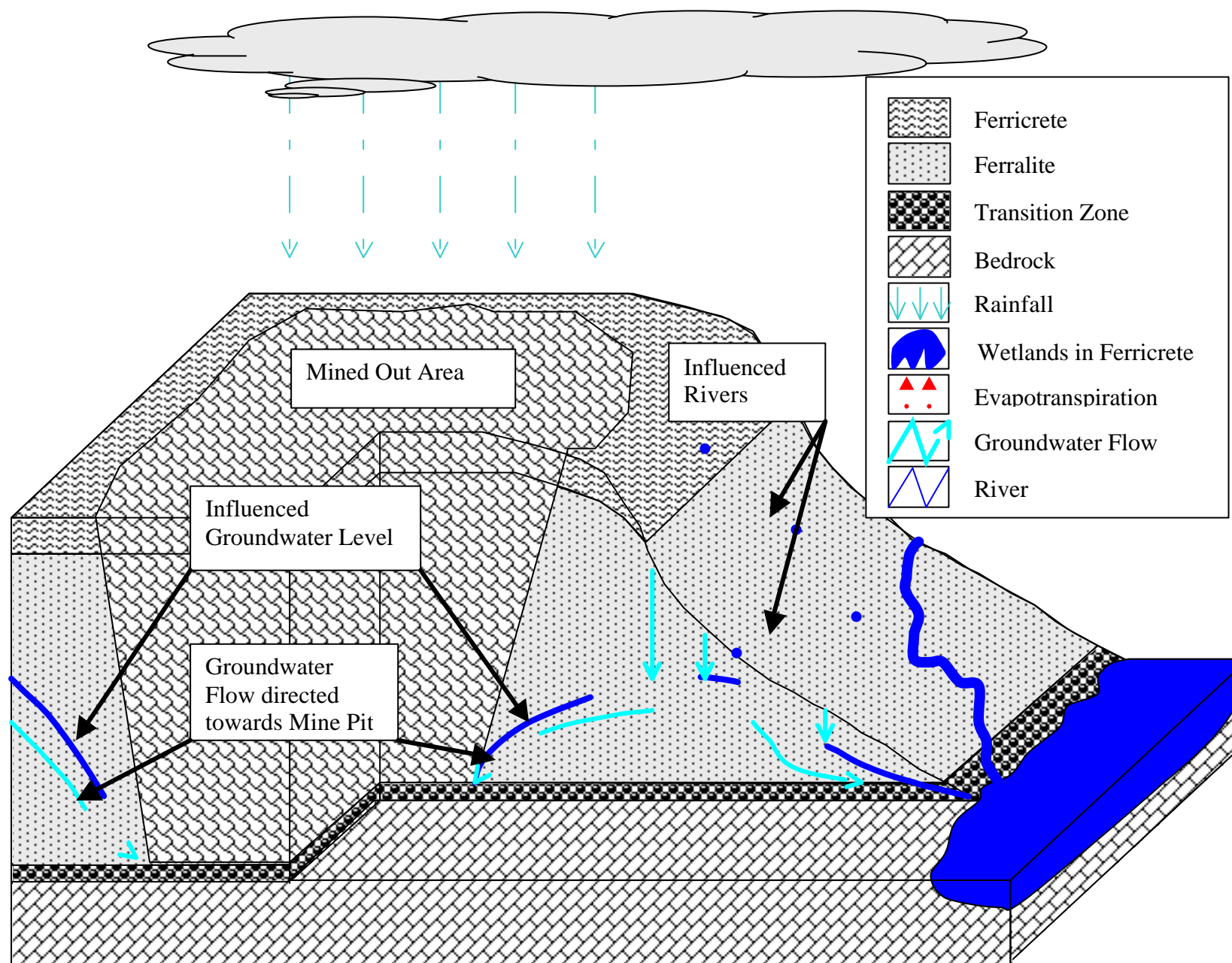
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Zone in the Ferricrete



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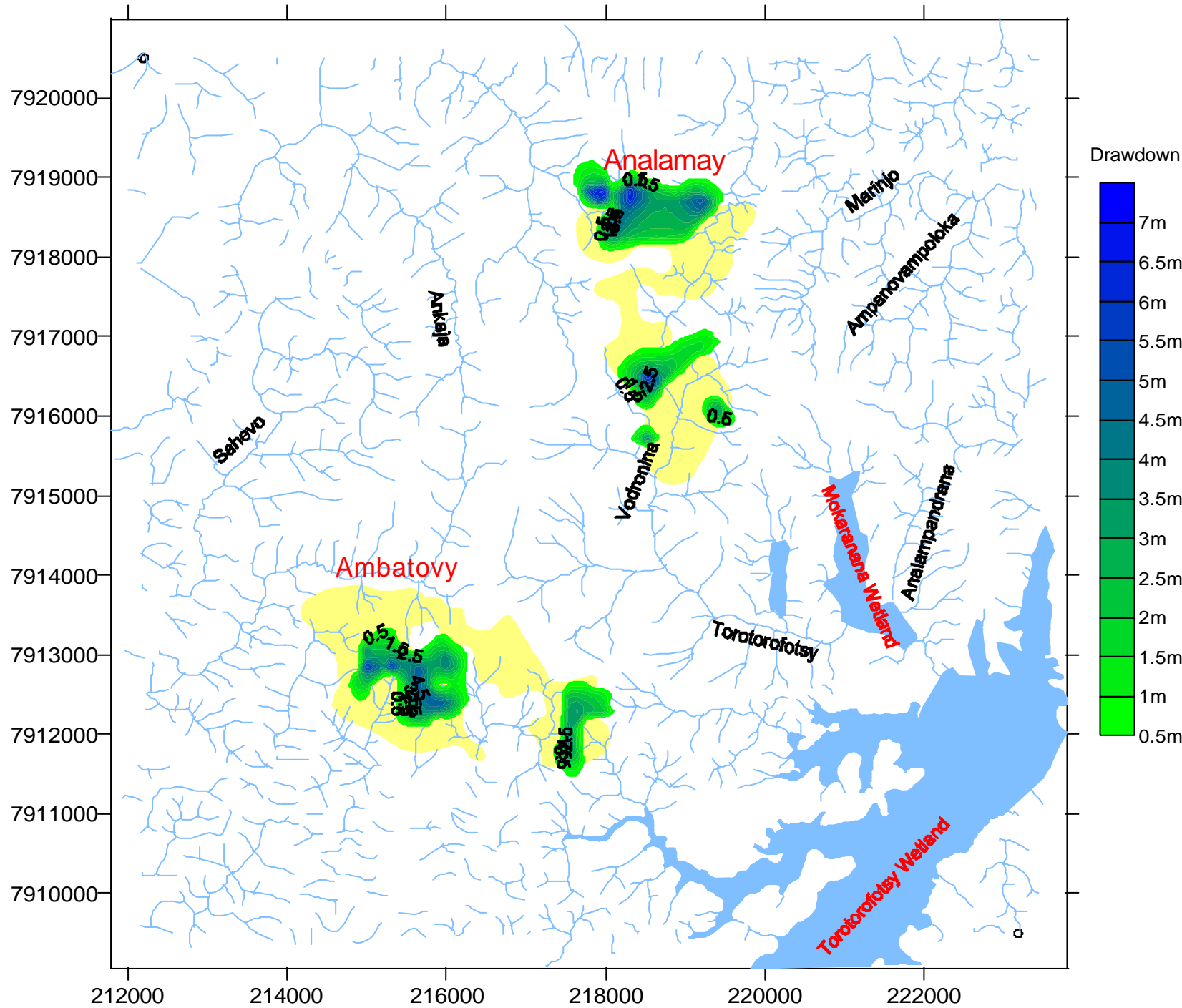
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Conceptual Influence of the Mining
Activities on the Groundwater
Environment



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- River
- Surface Water Body
- Ore Body Area

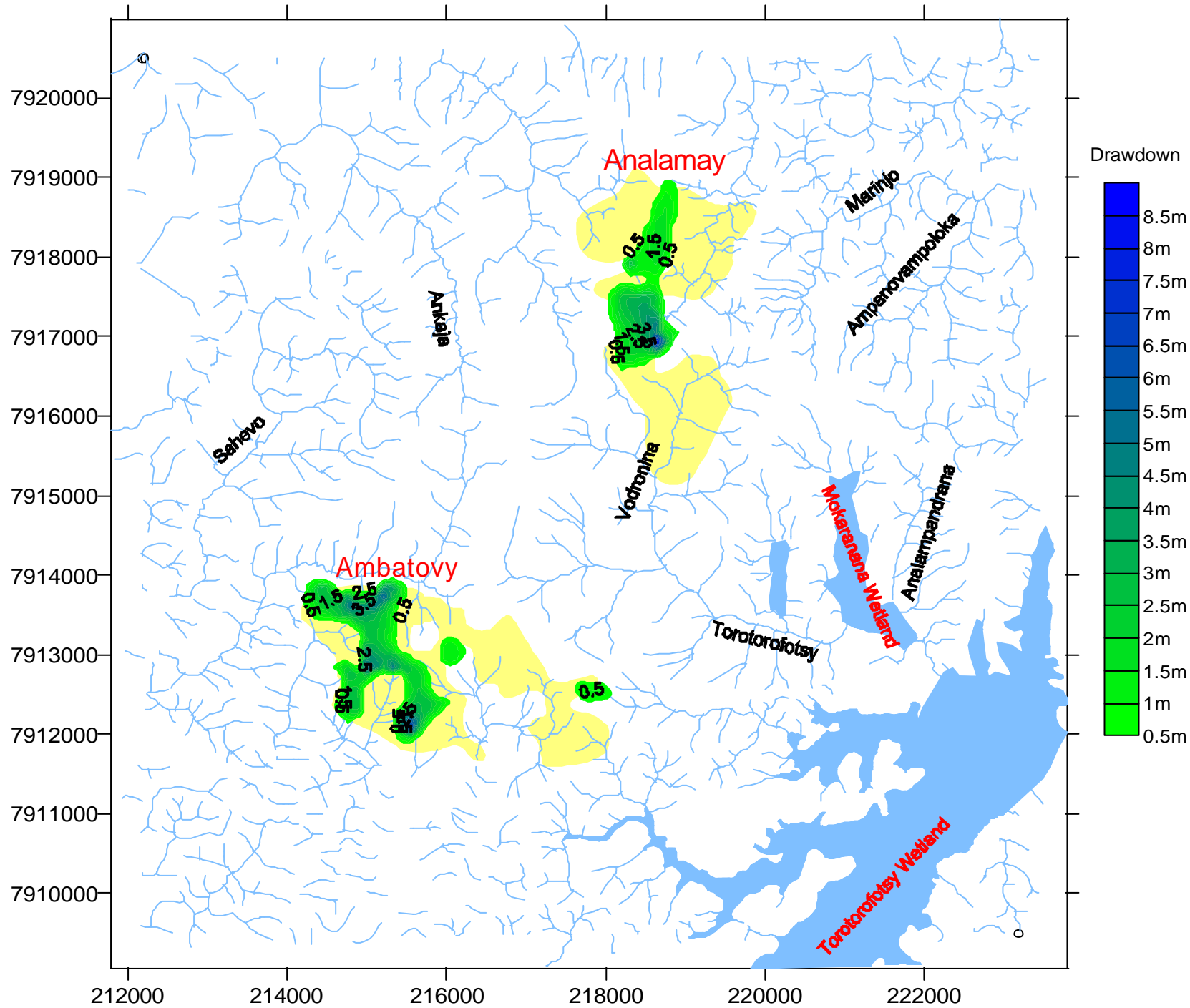
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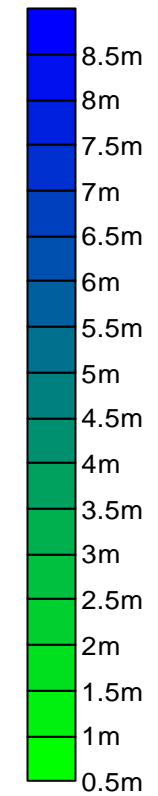
DRAWING TITLE:
Drawdown Cone Areas (Year 10)




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Drawdown




-  River
-  Surface Water Body
-  Ore Body Area

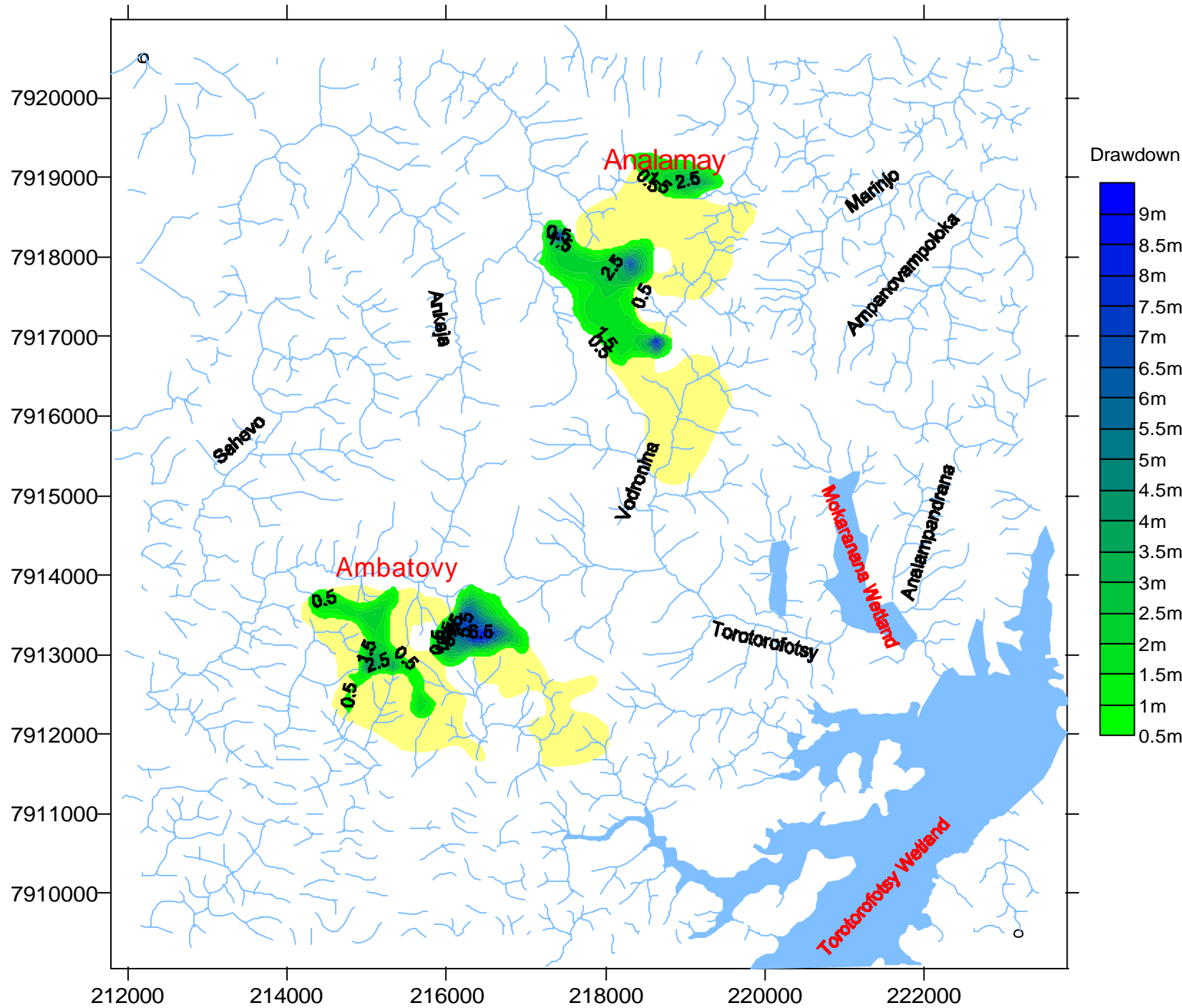
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DRAWING TITLE:
Drawdown Cone Areas (Year 20)

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- River
- Surface Water Body
- Ore Body Area

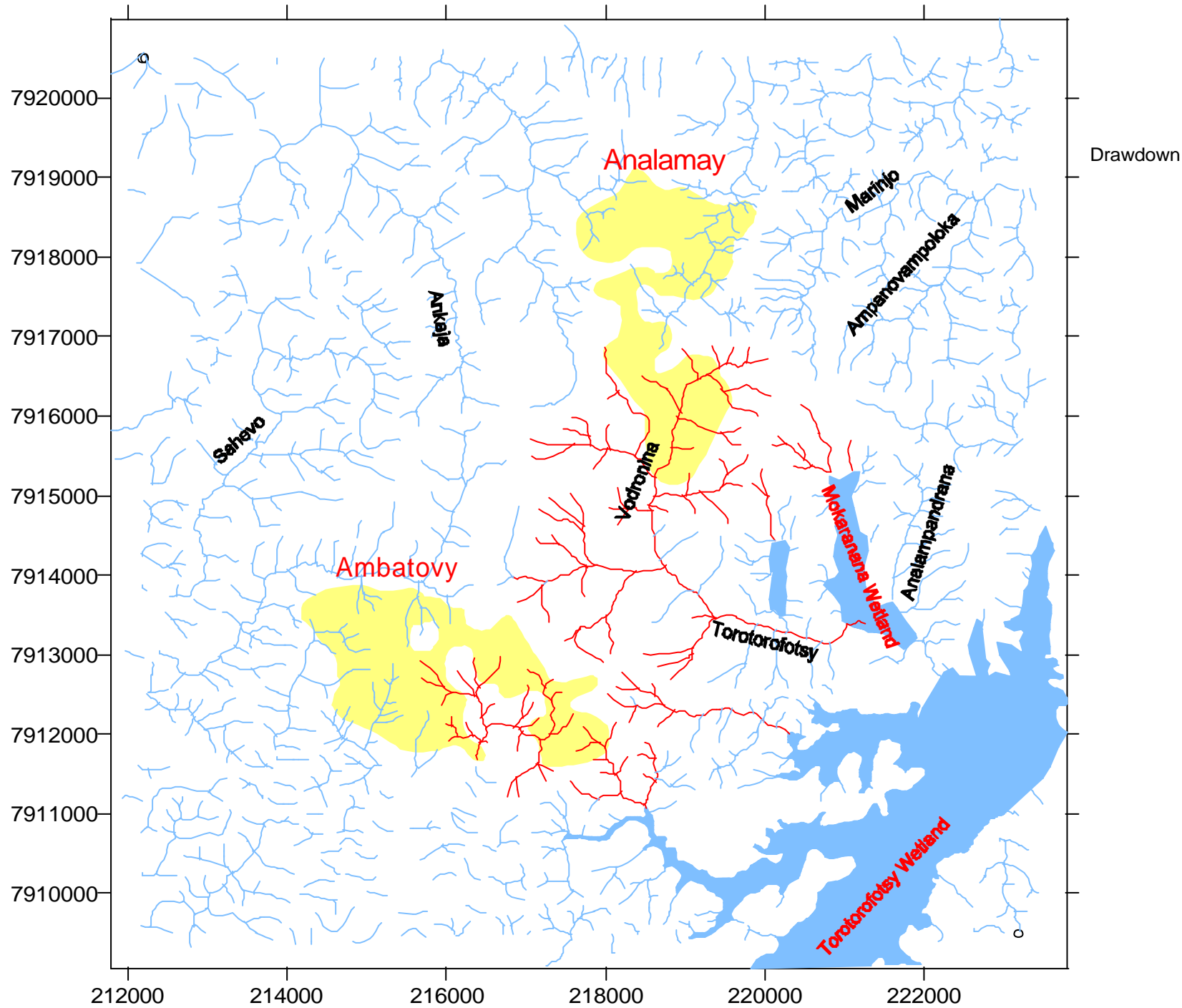
CLIENT:
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
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DRAWING TITLE:
Drawdown Cone Areas
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-  Influenced River
-  River
-  Surface Water Body
-  Ore Body Area

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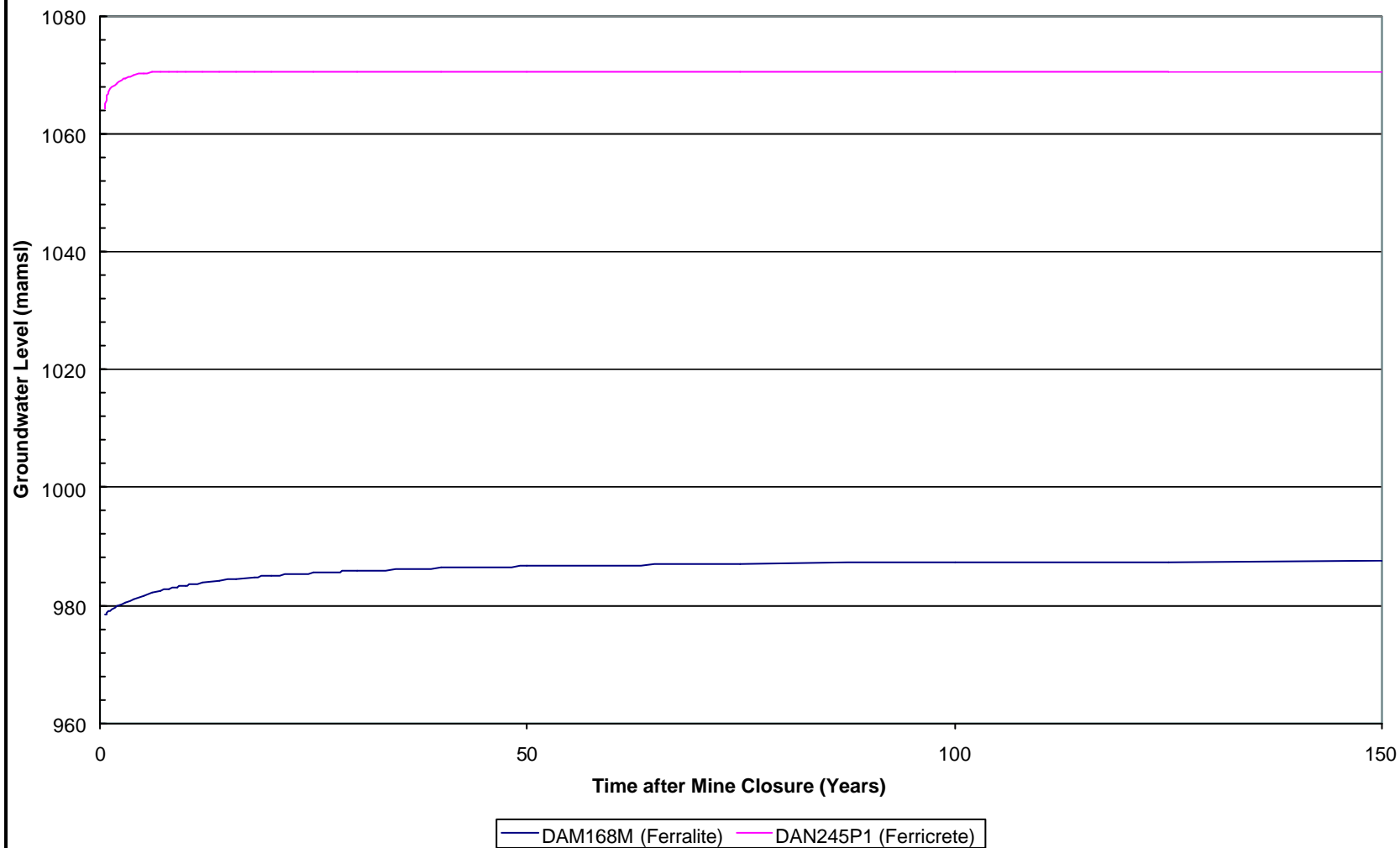
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DRAWING TITLE:
Rivers that are Expected
to be Influenced



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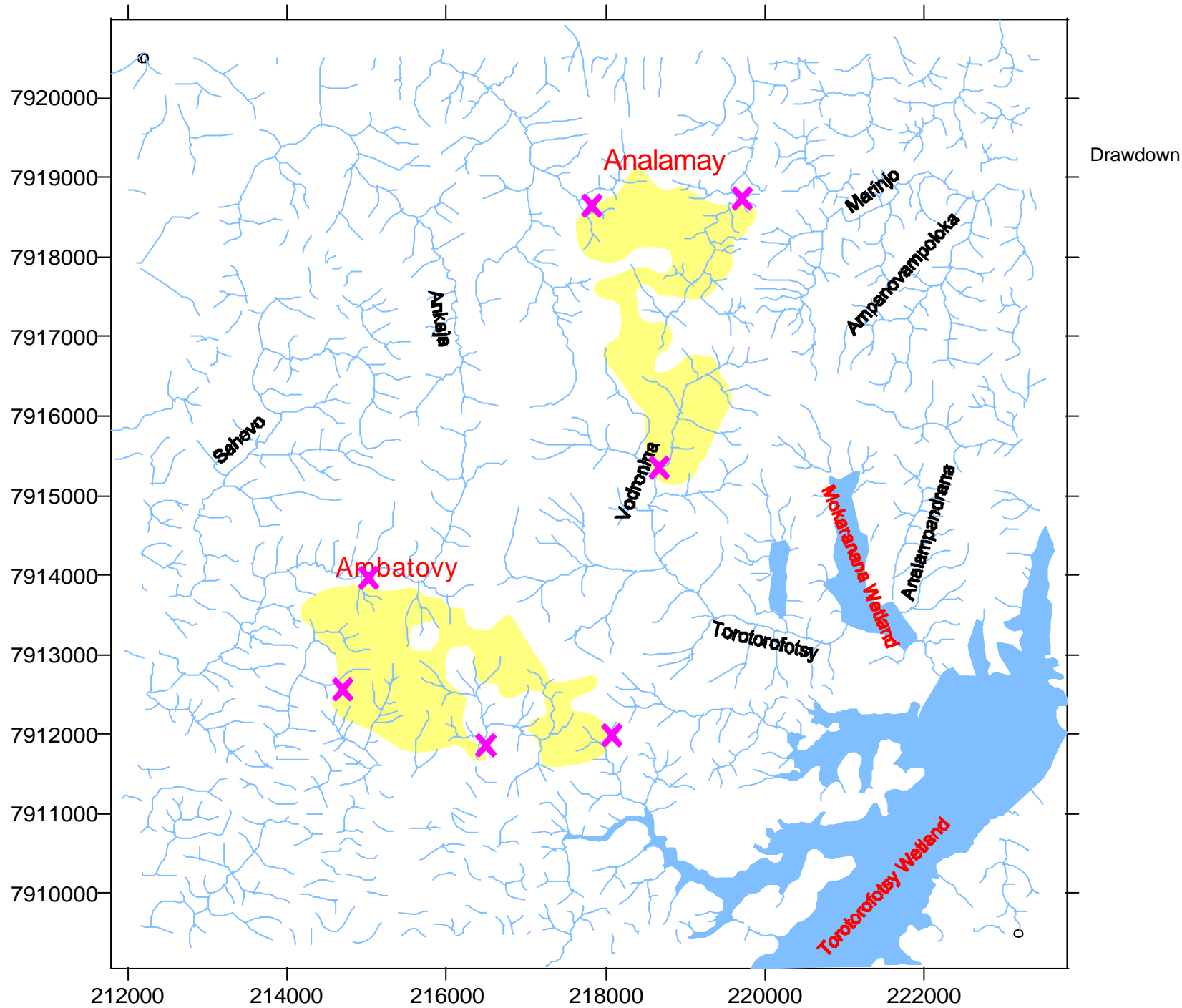
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DRAWING TITLE:
Groundwater Level
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Drawdown



- X Potential Decant Point
- River
- Surface Water Body
- Ore Body Area

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DRAWING TITLE:
Potential Decant Points

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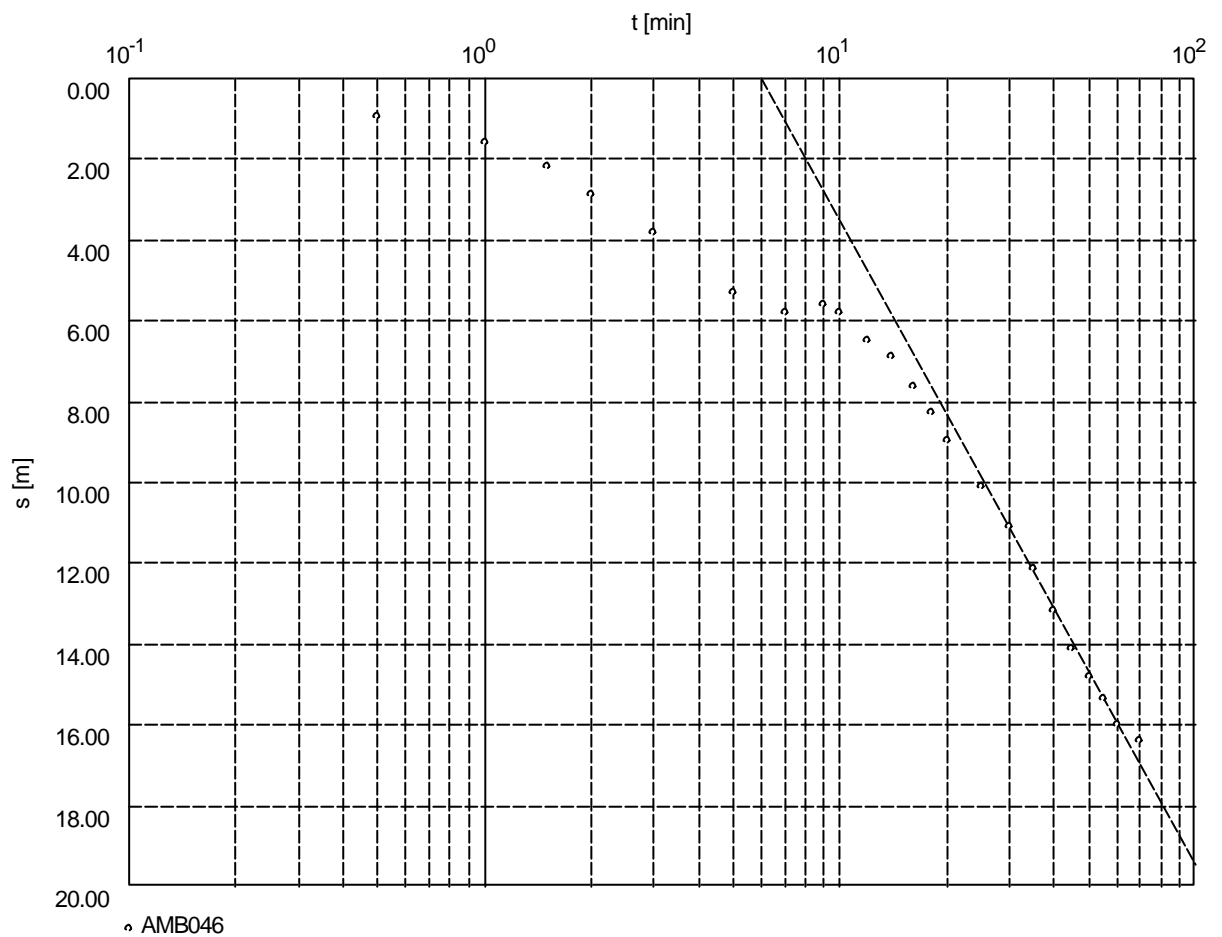
APPENDIX A:
AQUIFER TEST DATA

Pumping Test No. 1

Test conducted on: 22/04/2005

AMB046

Discharge 0.27 l/s


Transmissivity [m²/min]: 1.86×10^{-4}

Storativity: 3.91×10^{-1}

[illegible]

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Pumping test analysis

Recovery method after

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Page 1

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Date: 29.04.2005

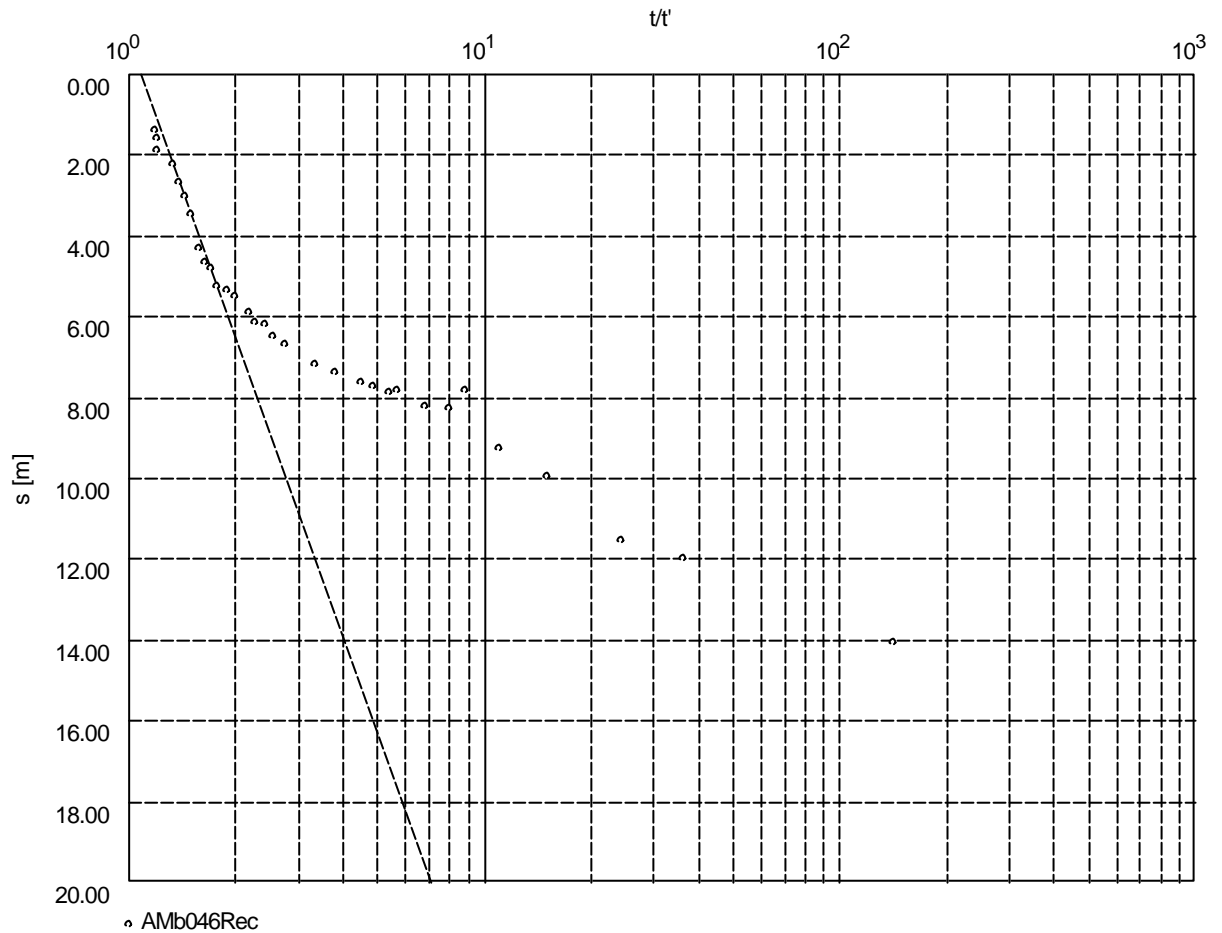
Pumping Test No. 1

Test conducted on: 22/04/2005

AMB046Rec

Discharge 0.27 l/s

Pumping test duration: 70.00 min

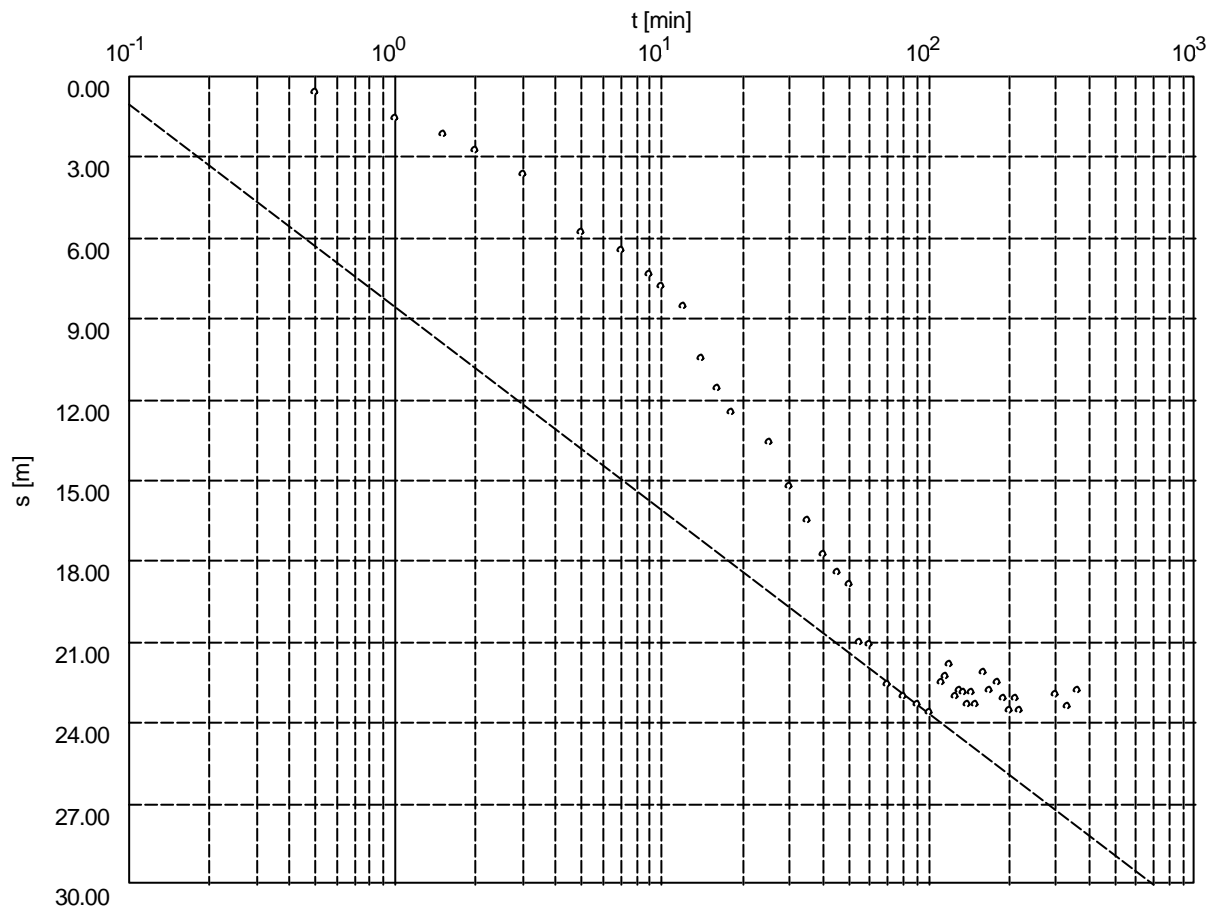
Transmissivity [m^2/min]: 1.21×10^{-4}

Pumping Test No. 1

Test conducted on: 22/05/2005

AMB113

Discharge 0.20 l/s


Transmissivity [m^2/min]: 2.91×10^{-4}

Storativity: 7.46×10^{-3}

Pumping Test No. 1		Test conducted on: 22/05/2005		
AMB113		AMB113		
Discharge 0.20 l/s		Distance from the pumping well 0.080 m		
Static water level: 16.930 m below datum				
	Pumping test duration	Water level	Drawdown	
	[min]	[m]	[m]	
2	0.50	17.500	0.570	
3	1.00	18.500	1.570	
4	1.50	19.100	2.170	
5	2.00	19.650	2.720	
6	3.00	20.600	3.670	
7	5.00	22.700	5.770	
8	7.00	23.400	6.470	
9	9.00	24.300	7.370	
10	10.00	24.700	7.770	
11	12.00	25.500	8.570	
12	14.00	27.370	10.440	
13	16.00	28.490	11.560	
14	18.00	29.390	12.460	
15	25.00	30.510	13.580	
16	30.00	32.180	15.250	
17	35.00	33.380	16.450	
18	40.00	34.690	17.760	
19	45.00	35.370	18.440	
20	50.00	35.820	18.890	
21	55.00	37.920	20.990	
22	60.00	38.040	21.110	
23	70.00	39.510	22.580	
24	80.00	39.970	23.040	
25	90.00	40.270	23.340	
26	100.00	40.560	23.630	
27	112.00	39.440	22.510	
28	115.00	39.200	22.270	
29	120.00	38.750	21.820	
30	125.00	39.950	23.020	
31	130.00	39.700	22.770	
32	135.00	39.800	22.870	
33	140.00	40.240	23.310	
34	145.00	39.800	22.870	
35	150.00	40.240	23.310	
36	160.00	39.030	22.100	
37	170.00	39.760	22.830	
38	180.00	39.460	22.530	
39	190.00	40.050	23.120	
40	200.00	40.450	23.520	
41	210.00	40.020	23.090	
42	220.00	40.440	23.510	
43	300.00	39.880	22.950	
44	330.00	40.300	23.370	
45	360.00	39.710	22.780	

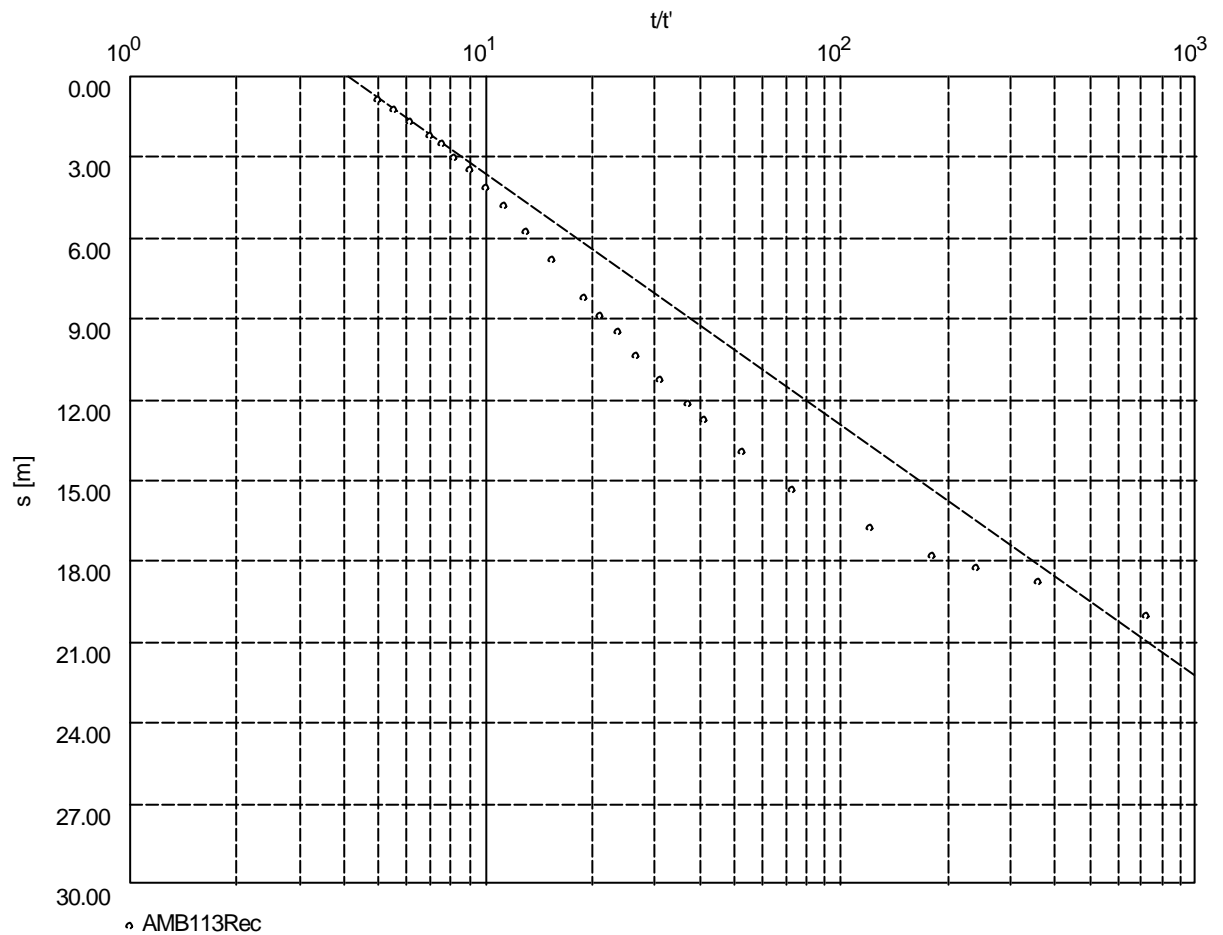
Pumping Test No. 1

Test conducted on: 22/04/2005

AMB113Rec

Discharge 0.20 l/s

Pumping test duration: 360.00 min

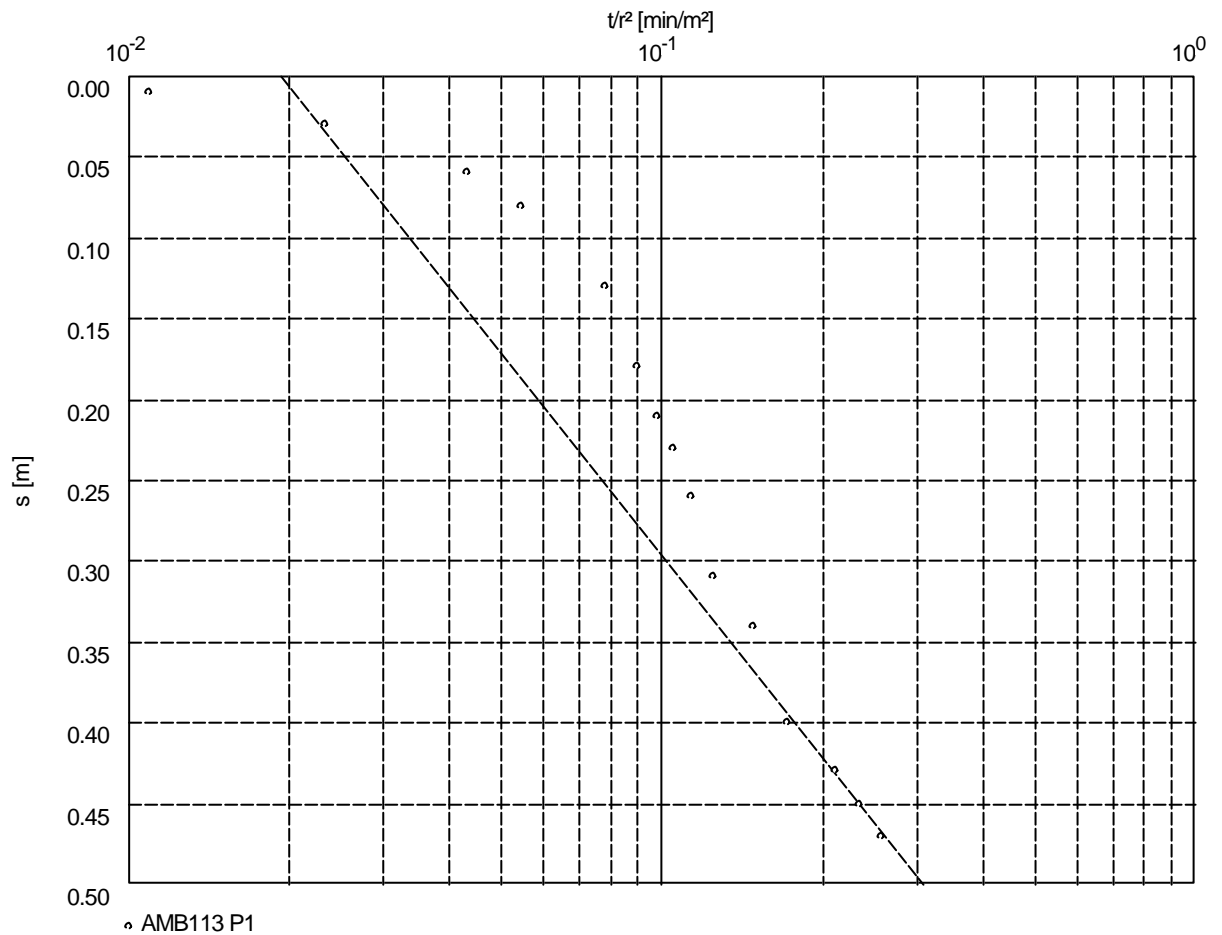

 Transmissivity [m^2/min]: 2.35×10^{-4}

Pumping Test No. 1

Test conducted on: 22/04/2005

AMP P1

Discharge 0.22 l/s


 Transmissivity [m²/min]: 5.83×10^{-3}

 Storativity: 2.52×10^{-4}

Test conducted on: 22/04/2005

AMB113 P1

Distance from the pumping well 35.810 m

Static water level: 11.430 m below datum

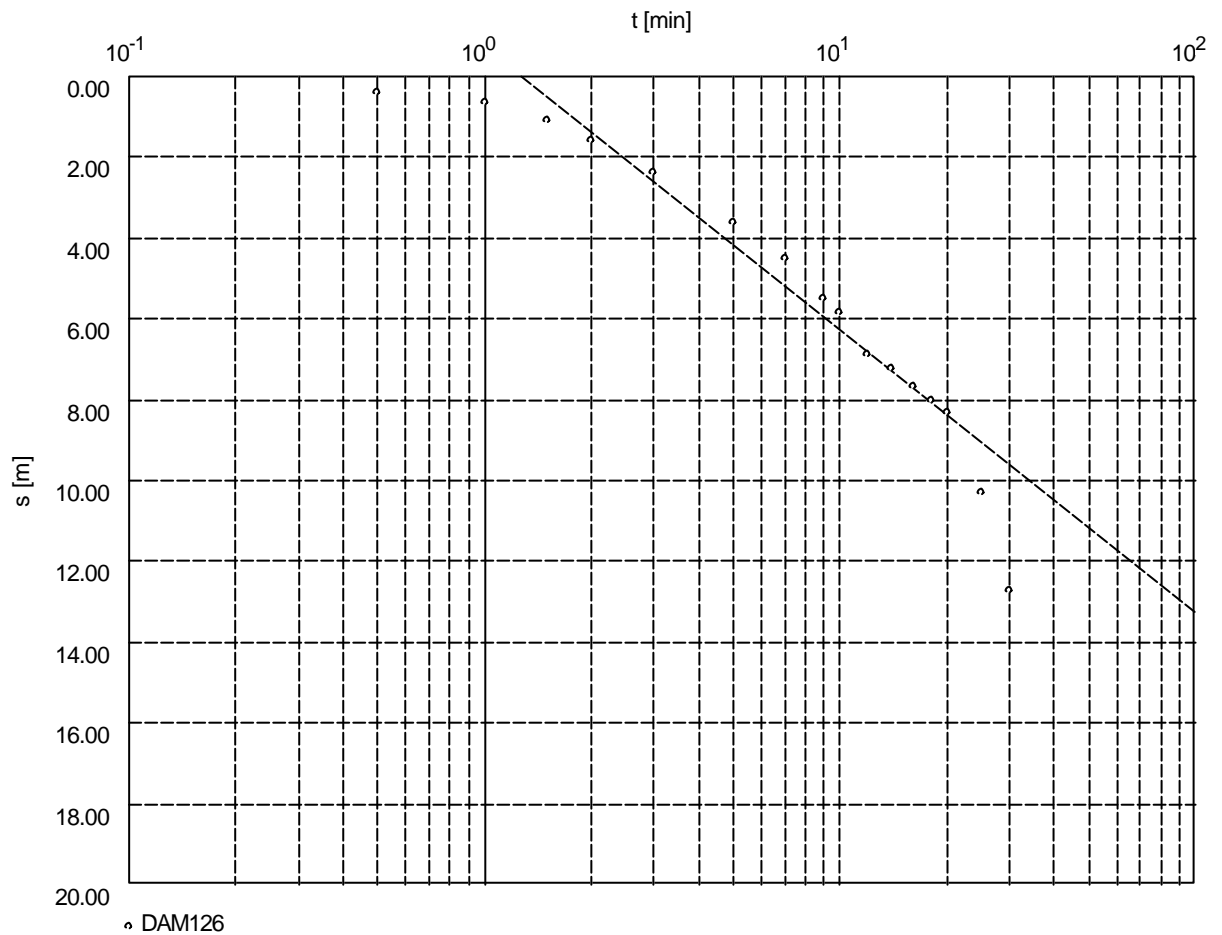
[illegible]

Pumping Test No. 1

Test conducted on: 20/04/2005

DAM126

Discharge 0.12 l/s


 Transmissivity [m^2/min]: 1.88×10^{-4}

 Storativity: 8.37×10^{-2}

[illegible]

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Evaluated by: MP

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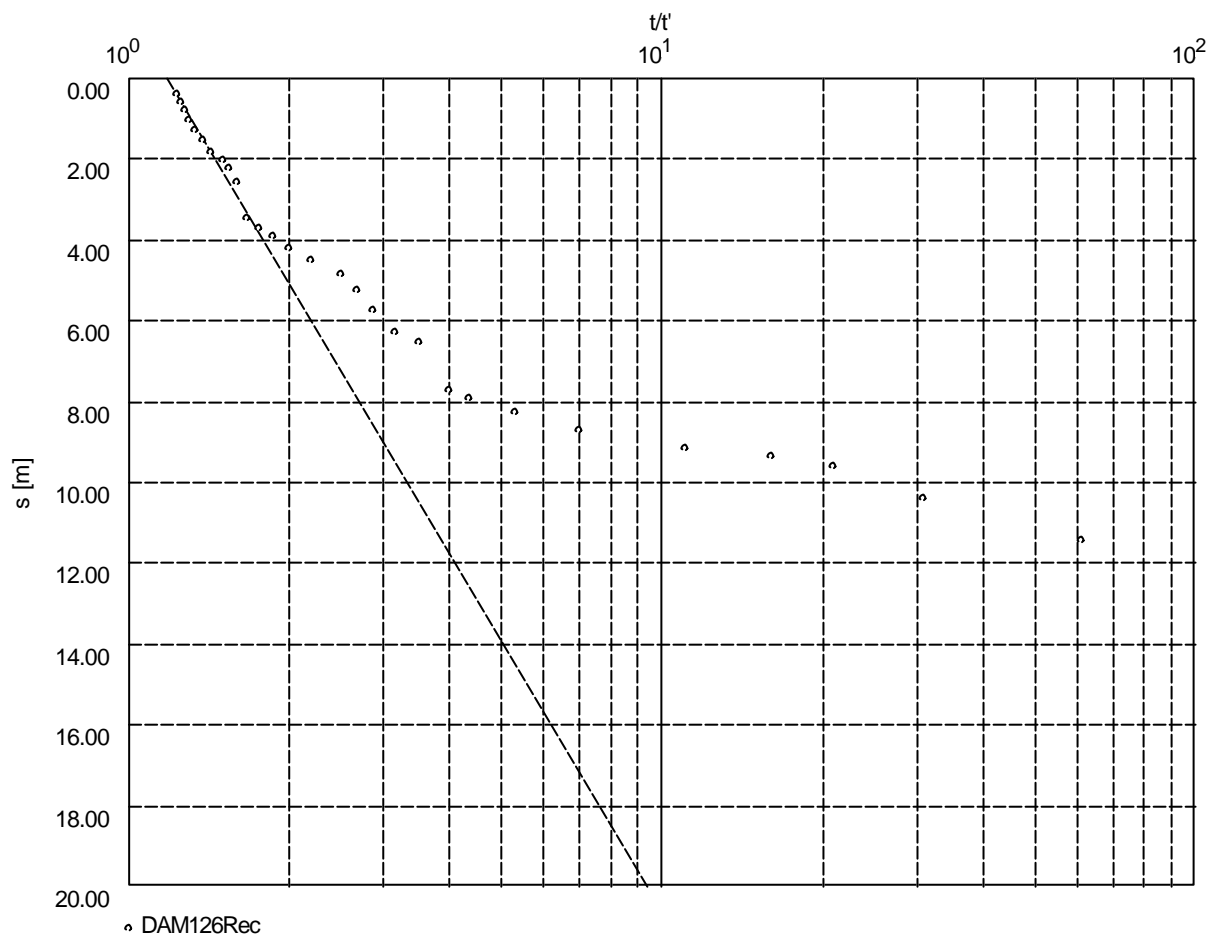
Pumping Test No. 1

Test conducted on: 20/04/2005

DAM126Rec

Discharge 0.12 l/s

Pumping test duration: 30.00 min

Transmissivity [m^2/min]: 5.94×10^{-5}

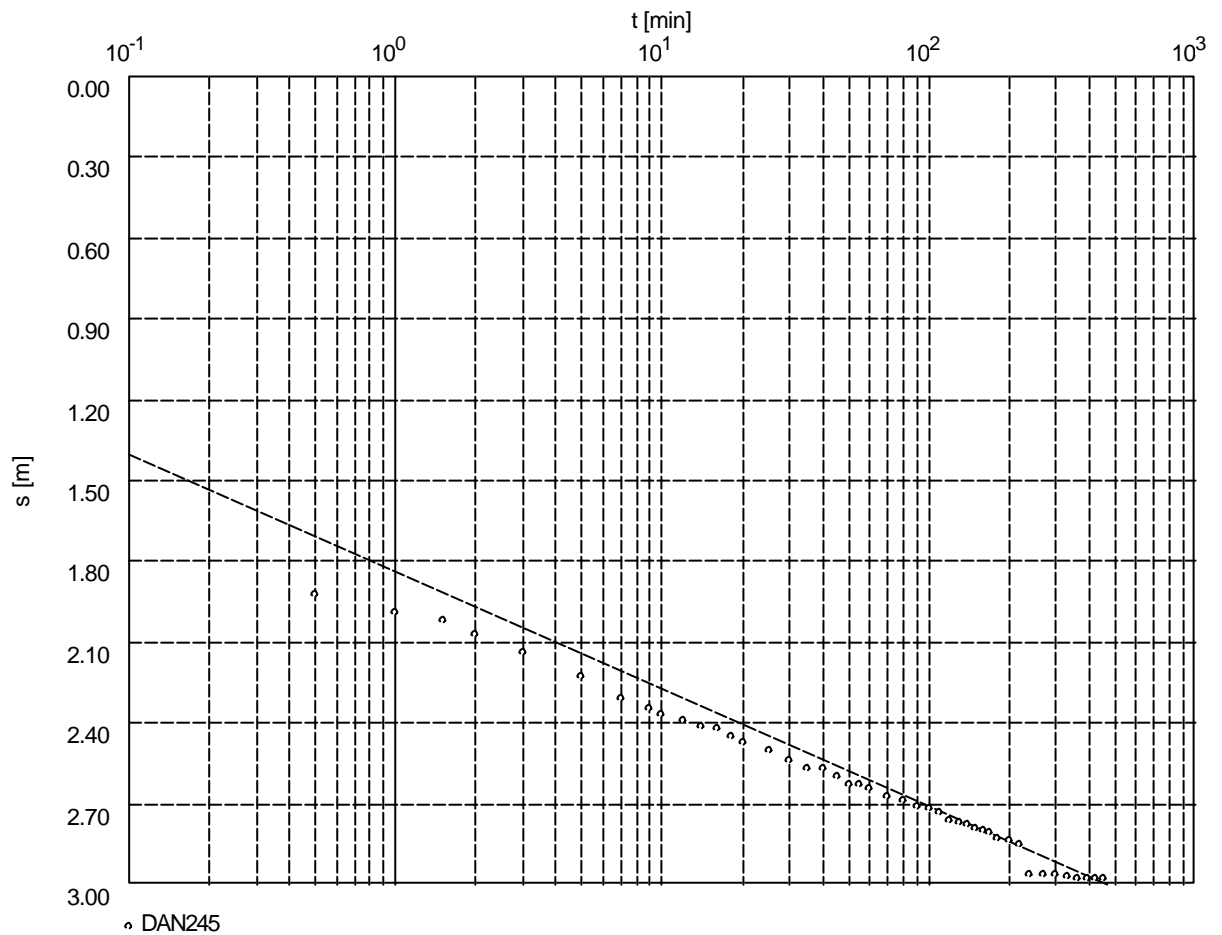
[illegible]

Pumping Test No. 1

Test conducted on: 19/04/2005

DAN245

Discharge 1.48 l/s


Transmissivity [m²/min]: 3.73×10^{-2}

Storativity: 7.95×10^{-4}

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				Evaluated by: MP	Date: 29.04.2005
Pumping Test No. 1			Test conducted on: 19/04/2005		
DAN245			DAN245		
Discharge 1.48 l/s			Distance from the pumping well 0.080 m		
Static water level: 21.680 m below datum					
	Pumping test duration	Water level	Drawdown		
	[min]	[m]	[m]		
2	0.50	23.600	1.920		
3	1.00	23.670	1.990		
4	1.50	23.700	2.020		
5	2.00	23.750	2.070		
6	3.00	23.820	2.140		
7	5.00	23.910	2.230		
8	7.00	23.990	2.310		
9	9.00	24.030	2.350		
10	10.00	24.050	2.370		
11	12.00	24.070	2.390		
12	14.00	24.090	2.410		
13	16.00	24.100	2.420		
14	18.00	24.130	2.450		
15	20.00	24.150	2.470		
16	25.00	24.180	2.500		
17	30.00	24.220	2.540		
18	35.00	24.250	2.570		
19	40.00	24.250	2.570		
20	45.00	24.280	2.600		
21	50.00	24.310	2.630		
22	55.00	24.310	2.630		
23	60.00	24.320	2.640		
24	70.00	24.350	2.670		
25	80.00	24.370	2.690		
26	90.00	24.390	2.710		
27	100.00	24.400	2.720		
28	110.00	24.410	2.730		
29	120.00	24.440	2.760		
30	130.00	24.450	2.770		
31	140.00	24.460	2.780		
32	150.00	24.470	2.790		
33	160.00	24.480	2.800		
34	170.00	24.490	2.810		
35	180.00	24.510	2.830		
36	200.00	24.520	2.840		
37	220.00	24.530	2.850		
38	240.00	24.640	2.960		
39	270.00	24.640	2.960		
40	300.00	24.640	2.960		
41	330.00	24.650	2.970		
42	360.00	24.660	2.980		
43	390.00	24.660	2.980		
44	420.00	24.660	2.980		
45	450.00	24.660	2.980		

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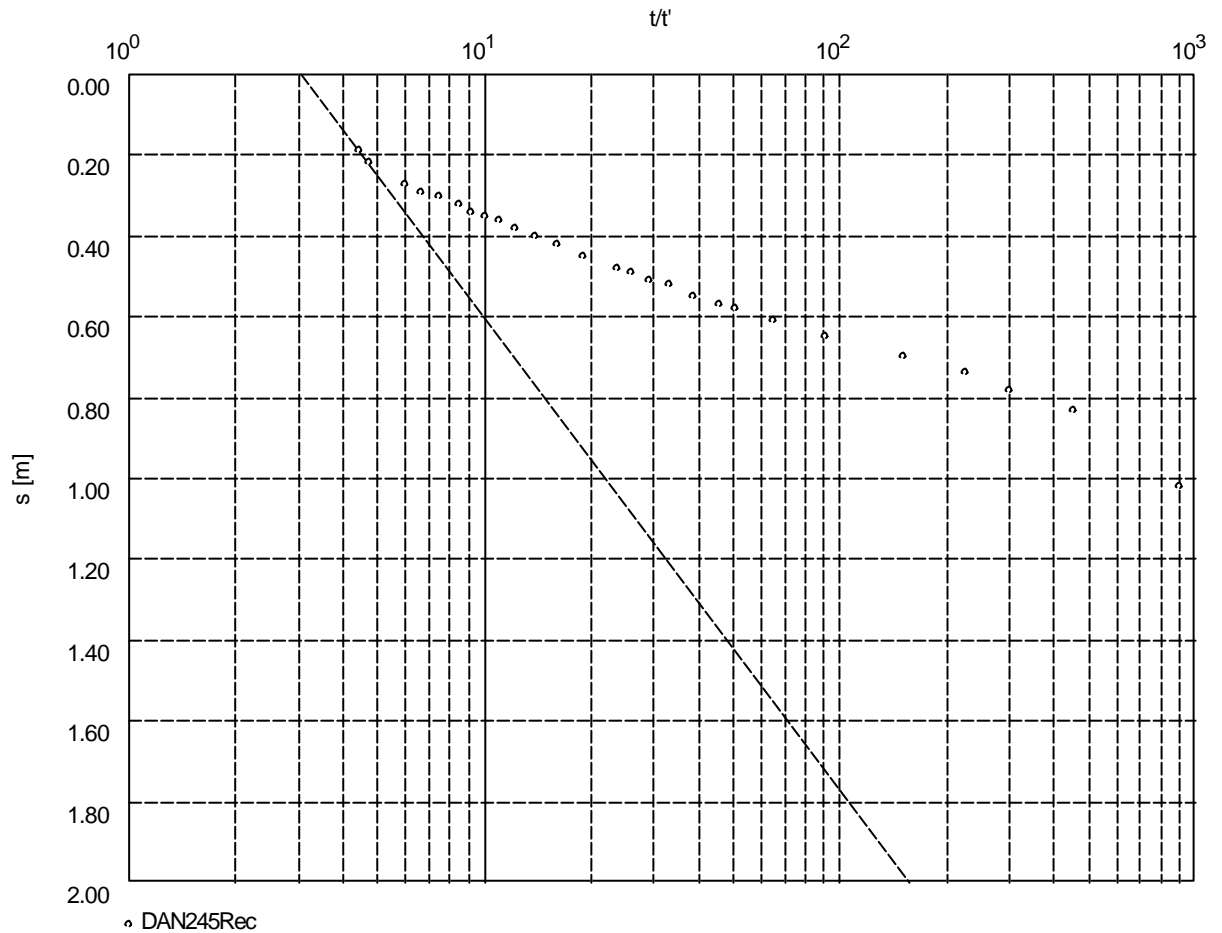
Pumping Test No. 1

Test conducted on: 19/04/2005

DAN245Rec

Discharge 1.48 l/s

Pumping test duration: 450.00 min

Transmissivity [m^2/min]: 1.38×10^{-2}

APPENDIX B:
UNSATURATED SEEPAGE MODELLING REPORT

**AMBATOVY PROJECT
MINE AREA
SEEPAGE ANALYSIS**

May 2005
W Dressel Pr Tech Eng

INTRODUCTION

GCS was appointed by Dynatec to conduct a seepage analysis for the mine runoff control and water supply facilities for the Ambatovy Project. The Ambatovy Project is located in the central east portion of Madagascar, about 130 km east of the capital Antananarivo.

SEEPAGE MODELLING

Methodology

Steady state seepage analyses were conducted utilising finite element software SEEP/W. The method is based on grid patterns, which divides the flow region into discrete elements. Material properties, such as permeability and volumetric water content, are specified for each element and boundary conditions (heads and flow rates) are set.

The purpose of the steady state analysis was to determine the position of the phreatic surface within the ponds and to estimate the volume of seepage water from the ponds into the foundation layers.

Model

The following ponds have been modelled for the operation phase of the mine:

- ❑ Analamay Northwest Mine runoff collection pond.
- ❑ Analamay Northwest Mine clarification pond.
- ❑ Analamay Northeast Mine runoff collection pond.
- ❑ Analamay Northeast Mine clarification pond.
- ❑ Analamay South Mine runoff collection pond.
- ❑ Analamay South Mine clarification pond.
- ❑ Ambatovy North Mine runoff collection pond.
- ❑ Ambatovy North Mine clarification pond.
- ❑ Ambatovy Waste Stockpile runoff collection pond.
- ❑ Ambatovy Waste Stockpile clarification pond.
- ❑ Ambatovy South Mine runoff collection pond.
- ❑ Ambatovy South Mine clarification pond.
- ❑ Ambatovy Southeast backfill runoff collection pond.

The following ponds and pits have been modelled for post closure:

- ❑ After closure the runoff water could be of an acceptable quality, it may be possible to breach the runoff collection pond walls and clarification pond walls to return the drainage paths to pre-mining conditions. All the runoff collection ponds and clarification ponds were modeled for closure conditions.

- Some areas of the pits will be flooded after closure of the mine, which will include Analamay west pit, Analamay east pit, Analamay south pit, Ambatovy central pit, Ambatovy west pit and Ambatovy south pit.

Refer to **Appendix A, Figure 1** and **Figure 2** for the pond and pit locations.

The analyses were performed assuming water levels at the normal maximum operating level for each of the ponds.

The information for the ponds used in the seepage analyses for operating conditions are summarised in **Table 1**.

Table 1: Pond Information Summary – Operating Conditions				
Pond Description	Elevation (m)			Water Area @ Max. Operating (m²)
	Embankment Crest	Max. Operating Pond	Min. Ground	
Analamay Northwest Mine runoff collection pond	1,019	1,012	998	270,000
Analamay Northwest Mine clarification pond	1,007	1,005	998	90,000
Analamay Northeast Mine runoff collection pond	1,030	1,021	1,002	70,000
Analamay Northeast Mine clarification pond	1,022	1,020	994	60,000
Analamay South Mine runoff collection pond	1,016	1,006	984	50,000
Analamay South Mine clarification pond	992	990	974	65,000
Ambatovy North Mine runoff collection pond	1,001	987	965	70,000
Ambatovy North Mine clarification pond	977	975	959	100,000
Ambatovy Waste Stockpile runoff collection pond	1,006	1,004	975	200,000
Ambatovy Waste Stockpile clarification pond	982	980	975	30,000
Ambatovy South Mine runoff collection pond	996	994	973	410,000
Ambatovy South Mine clarification pond	982	980	972	85,000
Ambatovy Southeast backfill runoff collection pond	1,012	1,010	990	50,000

The information for the ponds used in the seepage analyses for closure conditions are summarised in **Table 2**.

Table 2: Pond Information Summary – Closure Conditions				
Pond Description	Elevation (m)			Water Area @ Closure (m²)
	Breached Embankment Crest	Max. Water	Min. Ground	
Analamay Northwest Mine runoff collection pond	1,000	1,000	998	125,000
Analamay Northwest Mine clarification pond	1,000	1,000	998	65,000
Analamay Northeast Mine runoff collection pond	1,015	1,015	1,002	22,500

Table 2: Pond Information Summary – Closure Conditions				
Pond Description	Elevation (m)			Water Area @ Closure (m ²)
	Breached Embankment Crest	Max. Water	Min. Ground	
Analamay Northeast Mine clarification pond	1,000	1,000	994	4,000
Analamay South Mine runoff collection pond	995	995	984	9,500
Analamay South Mine clarification pond	980	980	974	8,150
Ambatovy North Mine runoff collection pond	970	970	965	7,900
Ambatovy North Mine clarification pond	960	960	959	13,350
Ambatovy Waste Stockpile runoff collection pond	978	978	975	6,150
Ambatovy Waste Stockpile clarification pond	978	978	975	14,250
Ambatovy South Mine runoff collection pond	975	975	973	114,100
Ambatovy South Mine clarification pond	975	975	972	63,150
Ambatovy Southeast backfill runoff collection pond	995	995	990	28,600

The information for the pits used in the seepage analyses for closure conditions are summarised in **Table 3**.

Table 3: Pit Information Summary – Closure Conditions				
Pond	Area (m ²)	Water Level (m)	Average Base Level (m)	Depth (m)
<u>Ambatovy Central Pit</u>				
1	260,751	1,026	1,008	18
<u>Ambatovy South Pit</u>				
15	15,368	1,020	996	24
16	60,593	996	987	9
17	16,329	1,002	993	9
18	16,843	1,014	1,000	14
20	2,041	1,002	990	12
<u>Ambatovy West Pit</u>				
10	32,384	1,002	994	8
11	35,835	1,008	993	15
12	6,393	1,008	990	18
13	2,100	1,002	1,001	1
14	3,240	1,020	1,019	1
21	11,701	1,008	990	18
<u>Analamay West Pit</u>				
2	297,249	1,056	1,043	13
3	78,563	1,014	1,008	6

Table 3: Pit Information Summary – Closure Conditions				
Pond	Area (m ²)	Water Level (m)	Average Base Level (m)	Depth (m)
4	92,597	1,044	1,008	36
5	95,864	1,080	1,050	30
9	3,996	1,038	1,037	1
<u>Analamay East Pit</u>				
19	56,150	1,026	1,008	18
<u>Analamay South Pit</u>				
6	11,651	1,080	1,079	1
7	145,700	1,014	1,002	12
8	4,097	1,020	1,014	6

Boundary Conditions

The models were setup to determine the volume of seepage from the runoff collection ponds, clarification ponds and pit areas. All the ponds were modeled using constant head boundary conditions.

Under drains and internal embankment drains with a zero pressure head boundary was used. This condition assumes that the drains will always be free draining and will not have a buildup of positive pore-water pressures.

Material Parameters

Several embankments will need to be constructed around the mine area to provide mine runoff control and operational storage for water supply. Knight Piesold recommended that waste material from initial plant construction activities or mining activities should be used for embankment fill material.

The embankment design will consist of a homogeneous type dam with a vertical sand filter chimney and blanket drain. The upstream zone will consist of select local fill (weathered gabbro), while the downstream will consist of random local fill (weathered gabbro, ferralite or other local suitable materials). Riprap will be applied to the upstream slopes for erosion protection. As the embankments will be overflow structures, the crests and downstream slopes will be armoured with concrete covered stepped gabion mats.

A typical foundation profile as reported by Golder (January 1999) was used for the analyses, and is as follows:

- **Ferralite or alluvium** - Clayey homogeneous layer with an average depth of 40m along the higher ground and it was assumed that the valley areas are covered by an average of

5m deep ferralite of alluvium. In some of the valley areas the soil could be eroded to bedrock. Hydraulic conductivity for the ferralite was 1.6×10^{-4} cm/s.

- ❑ **Transition zone** – The transition zone consists of saprolite and weathered bedrock layers with an average thickness of approximately 2m. Hydraulic conductivity for the transition zone ranged from 4.7×10^{-5} cm/s to 2.4×10^{-3} cm/s.
- ❑ **Bedrock** – The bedrock layer is primarily rock such as peridotite and gabbro with a layer thickness of approximately 30m. Hydraulic conductivity for the bedrock ranged from 2.5×10^{-3} cm/s to 5.6×10^{-3} cm/s.

The above quoted values for the hydraulic conductivity of the bedrock as reported by Golder are unrealistic for bedrock and it is believed that this might be the hydraulic conductivity in the fractures. It is therefore suggested that a lower value of 1.5×10^{-6} cm/s be used in the seepage analysis for the bedrock layer.

Material properties of the embankments and the founding horizon are summarised in **Table 4** below:

Table 4: Material Properties			
Material Type	Permeability	K_y/K_x	Data Source
Runoff Collection and Clarification Ponds			
Wall upstream zone	1.0×10^{-8} m/s	1	Knight Piesold
Wall downstream zone	1.0×10^{-7} m/s	1	Knight Piesold
Sand (filter drain)	1.1×10^{-4} m/s	1	Estimated
Ferralite / alluvium	5.0×10^{-6} m/s	1	Golder
Bedrock	1.5×10^{-8} m/s	1	Estimated
Pits			
Transition zone	1.0×10^{-5} m/s	1	Golder
Ferralite / alluvium	5.0×10^{-6} m/s	1	Golder
Bedrock	1.5×10^{-8} m/s	1	Estimated

The foundation profile used in the seepage analyses was generalised and it should be noted that the actual profile could vary. A detailed site investigation will be required to determine the exact foundation profile at each of the pond locations.

MODEL RESULTS

A series of flux sections, to measure seepage from the ponds, were placed in the foundation layer. The flow rates derived from the simulations were converted to calculate the total seepage volumes.

The average total seepage volumes during operating conditions from the ponds to the foundation are summarised in **Table 5** below:

Table 5: Summary of Seepage Volumes for Ponds – Operating Conditions		
Pond Description	Seepage (m³/month)	Seepage (m³/day)
Analamay Northwest Mine runoff collection pond	913	30.5
Analamay Northwest Mine clarification pond	150	5.0
Analamay Northeast Mine runoff collection pond	999	33.3
Analamay Northeast Mine clarification pond	788	26.3
Analamay South Mine runoff collection pond	396	13.2
Analamay South Mine clarification pond	206	6.9
Ambatovy North Mine runoff collection pond	652	21.7
Ambatovy North Mine clarification pond	408	13.6
Ambatovy Waste Stockpile runoff collection pond	3,337	111.2
Ambatovy Waste Stockpile clarification pond	100	3.3
Ambatovy South Mine runoff collection pond	3,006	100.2
Ambatovy South Mine clarification pond	150	5.0
Ambatovy Southeast backfill runoff collection pond	265	8.8

The average total seepage volumes during closure conditions from the ponds to the foundation are summarised in **Table 6** below:

Table 6: Summary of Seepage Volumes for Ponds - Closure Conditions		
Pond Description	Seepage (m³/month)	Seepage (m³/day)
Analamay Northwest Mine runoff collection pond	23.4	0.8
Analamay Northwest Mine clarification pond	12.1	0.4
Analamay Northeast Mine runoff collection pond	92.9	3.1
Analamay Northeast Mine clarification pond	5.5	0.2
Analamay South Mine runoff collection pond	30.7	1.0
Analamay South Mine clarification pond	11.0	0.4
Ambatovy North Mine runoff collection pond	8.2	0.3
Ambatovy North Mine clarification pond	0.7	0.02
Ambatovy Waste Stockpile runoff collection pond	1.9	0.06
Ambatovy Waste Stockpile clarification pond	4.5	0.2
Ambatovy South Mine runoff collection pond	21.4	0.7

Table 6: Summary of Seepage Volumes for Ponds - Closure Conditions		
Pond Description	Seepage (m ³ /month)	Seepage (m ³ /day)
Ambatovy South Mine clarification pond	11.8	0.4
Ambatovy Southeast backfill runoff collection pond	29.5	1.0

The average total seepage volumes from the pits after closure to the foundation are summarised in **Table 7** below:

Table 7: Summary of Seepage Volumes for Pits – Closure Conditions		
Pond	Seepage (m ³ /month)	Seepage (m ³ /day)
<u>Ambatovy Central Pit</u>		
1	1,426	47.5
<u>Ambatovy South Pit</u>		
15	152	5.1
16	83	2.7
17	22	0.7
18	55	1.8
20	5	0.2
<u>Ambatovy West Pit</u>		
10	36	1.2
11	135	4.5
12	35	1.2
13	1	0.03
14	1	0.03
21	64	2.1
<u>Analamay West Pit</u>		
2	839	28
3	53	1.8
4	2,097	69.9
5	1,495	49.8
9	1	0.03
<u>Analamay East Pit</u>		
19	307	10.2
<u>Analamay South Pit</u>		
6	3	0.1
7	350	11.7
8	3	0.1

Typical graphical views of the analysed ponds and pits are presented in **Appendix A**.

CONCLUSIONS

Based on the numerical modeling exercise the following conclusions can be made:

The results indicate that the volumes of water that will be lost to seepage from the runoff collection ponds and clarification ponds will vary and is a function of the water depth and the basin area covered by water.

The seepage volumes from the runoff collection ponds, during operational conditions, will vary between approximately 110 m³/day to 20 m³/day.

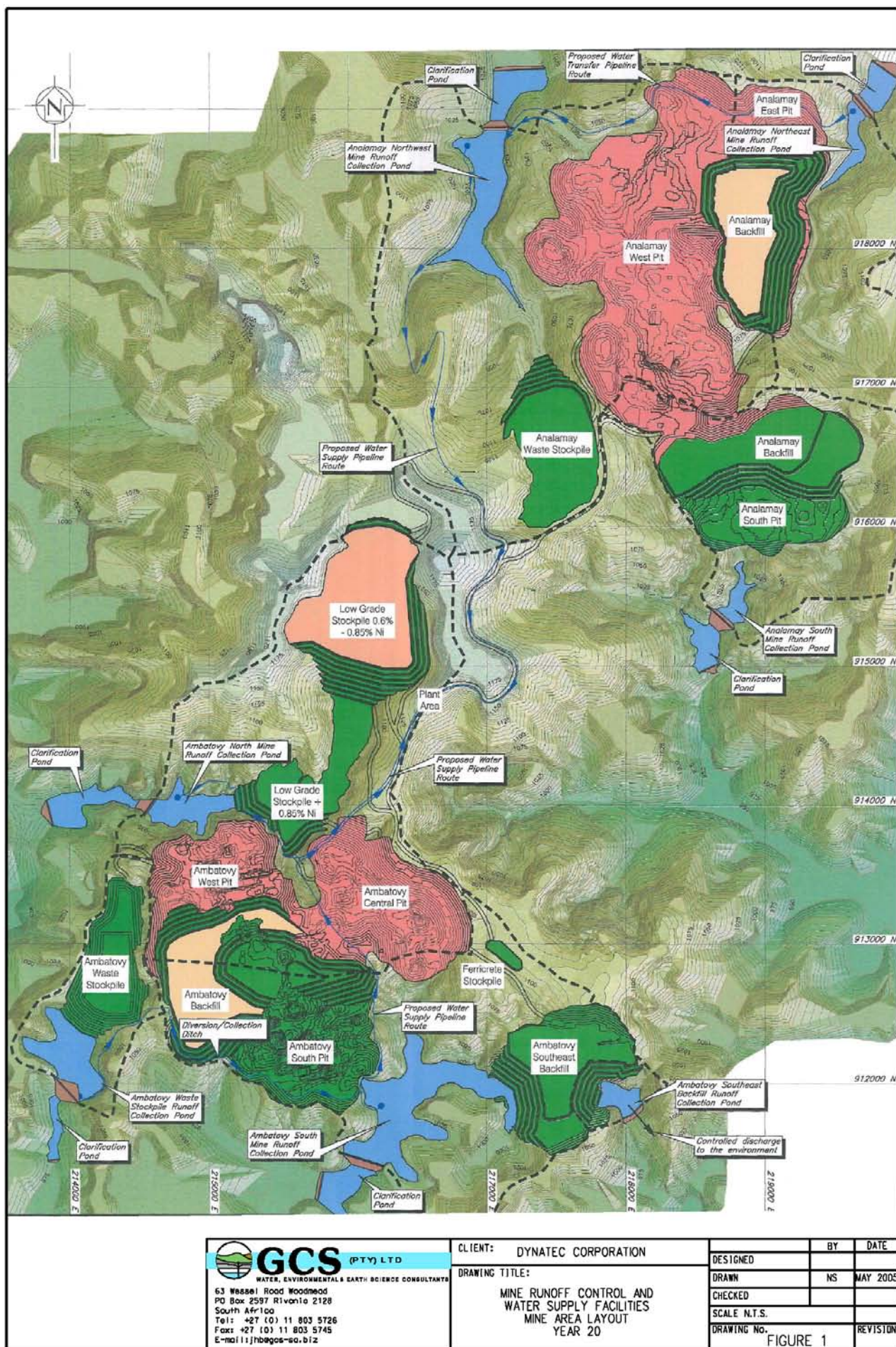
The seepage volumes from the clarification ponds, during operational conditions, will vary between approximately 30 m³/day to 3 m³/day.

It can be seen that the hydraulic conductivity of the bedrock as reported by Golder is very high for bedrock. It was therefore assume that the conductivity was measured in the fractures. It is recommended that the fractures be sealed by means of grouting of similar methods if the fractures are exposed within the basin areas of the ponds to minimize the seepage losses.

The seepage volumes from the runoff collection ponds and clarification ponds after closure will reduce as it is proposed that the pond walls would be breached to return the streams to its natural conditions.

Some of the open pit areas will not be backfilled for closure and ponds will form within the pits from surface runoff water. The seepage volume from the pit areas will vary from 70 m³/day to 0.03 m³/day.

Limited geotechnical information for the foundation horizon and embankment material was available to GCS during the seepage modeling exercise.



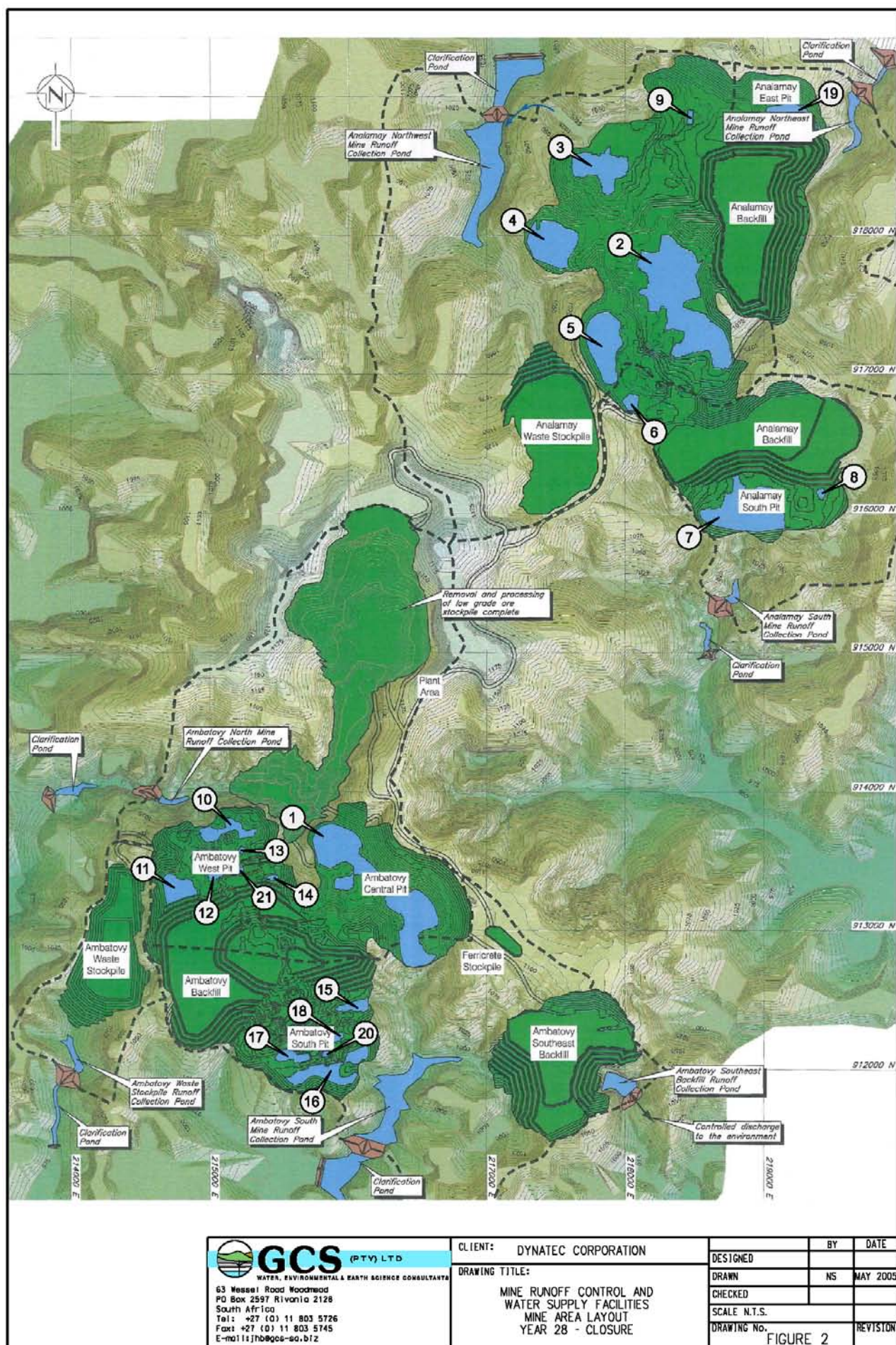


Figure 3: Typical Seepage – Runoff Collection Ponds and Clarification Ponds

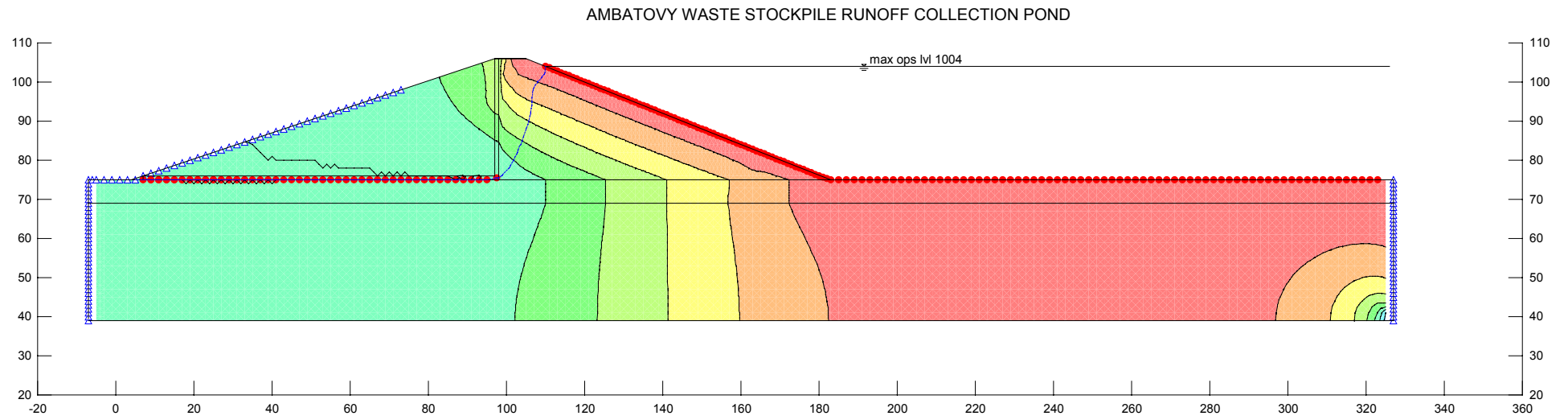


Figure 4: Typical Seepage – Runoff Collection Ponds and Clarification Ponds

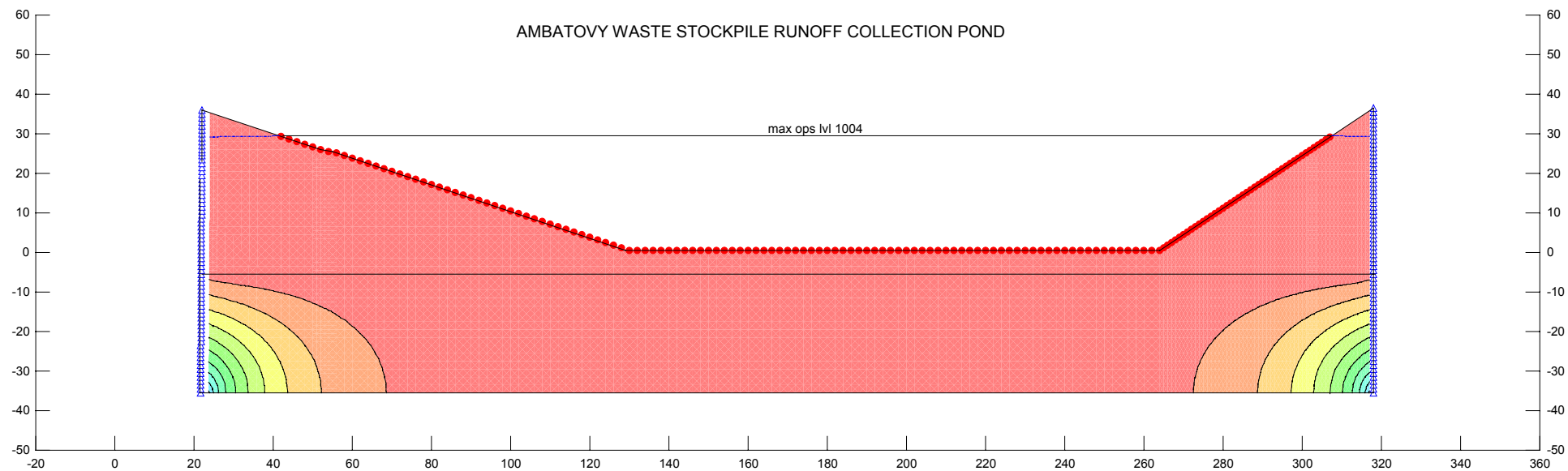


Figure 5: Typical Seepage – Runoff Collection Ponds and Clarification Ponds

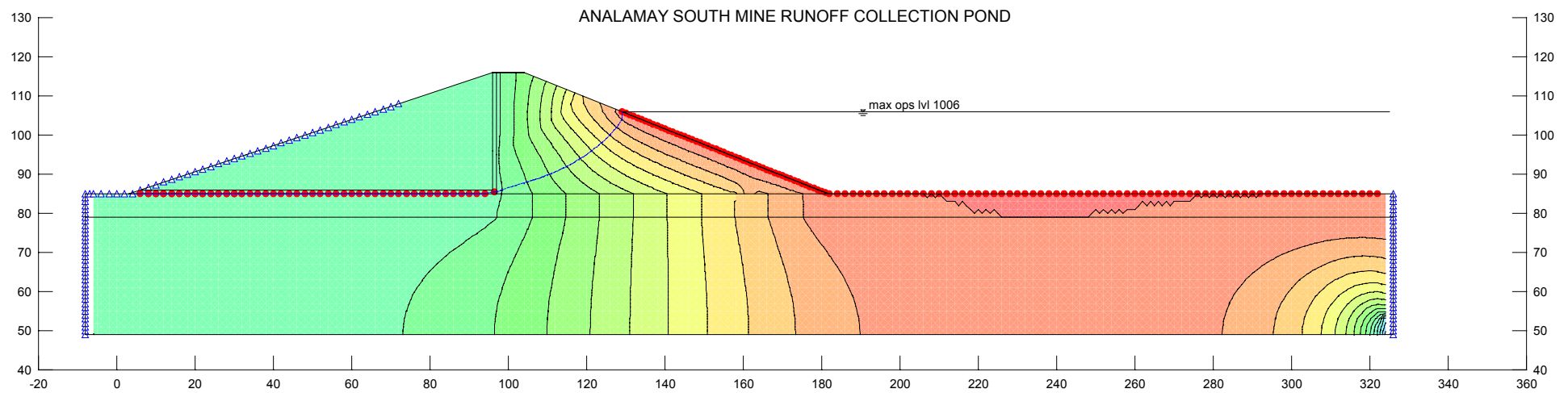


Figure 6: Typical Seepage – Runoff Collection Ponds and Clarification Ponds

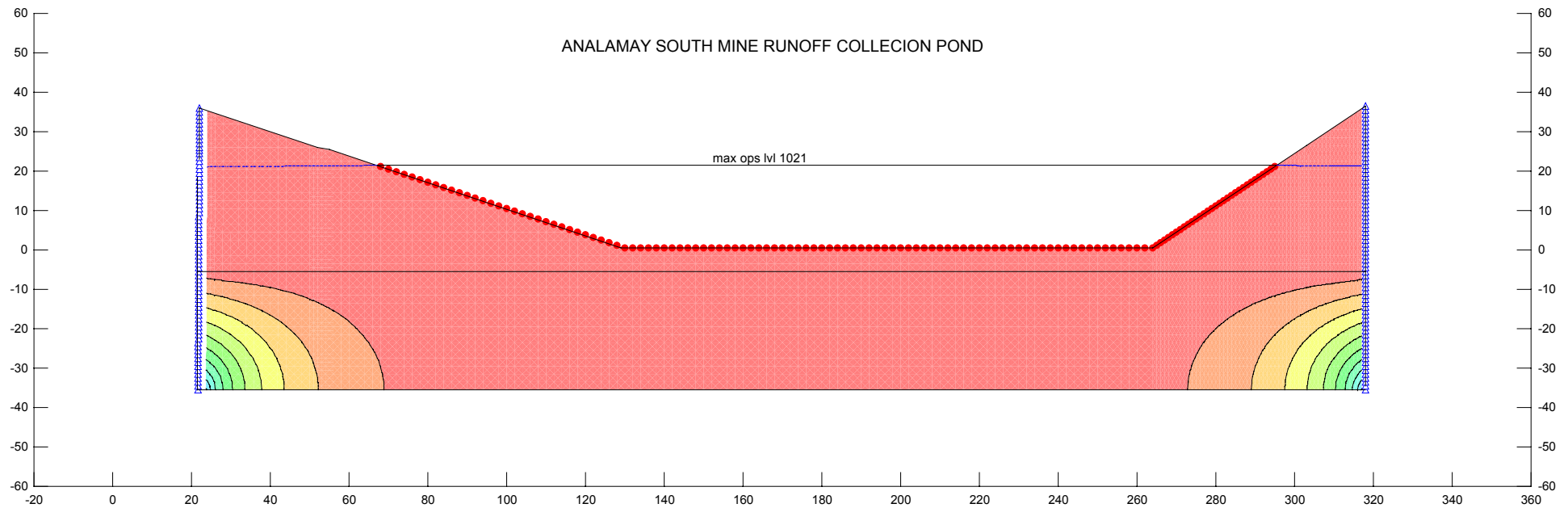
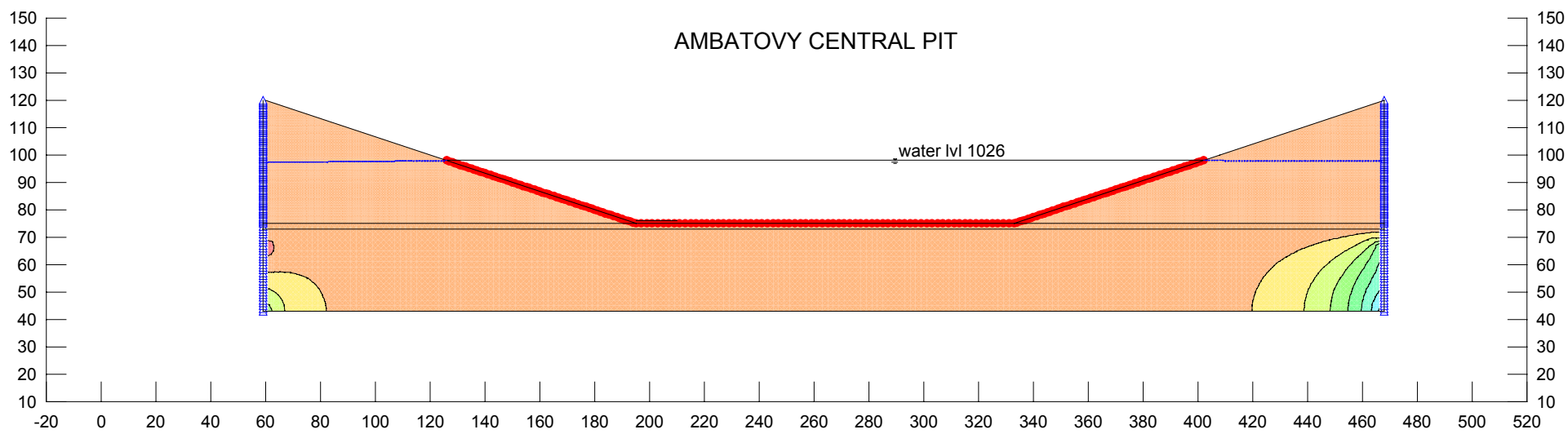


Figure 7: Typical Seepage – Pit at Closure Conditions



VOLUME I

APPENDIX 7.1

ATTACHMENT 2

**GROUNDWATER QUALITY SAMPLING, MARCH TO APRIL, 2005
REVISED JULY 2005**

Our Ref: 2004.02.110

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Ambatovy & Analamay Mining Project - Madagascar

Groundwater Quality Sampling
March to April 2005
(Revised July 2005)

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Appendix A: Groundwater Chemistry Analysis Certificates	
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1. Introduction and Terms of Reference

GCS (Pty) Ltd. was contracted by Dynatec to perform a hydrogeological investigation for the Ambatovy & Analamay mining project in Madagascar. The investigation commenced in June 2004. The aim of the investigation was to characterise the hydrogeological environment and to predict the potential influence of the proposed mining activities on the groundwater regime.

The initial study was completed in December 2004 (Refer to GCS Report 2004.02.110, December 2004). The investigation was performed during the dry season when most of the rainwater that recharged into the overlying ferricrete layer had already exited from the groundwater system in the form of spring flow. Only a small percentage of the infiltrating water recharges the underlying ferralite, transition zone, and base rock through vertical seepage. Due to this, little water was intercepted in the monitoring boreholes at the end of the dry season when the aquifer tests were performed and very little useable data could be obtained.

Therefore, it was decided to perform additional groundwater quality sampling during the rainy season (April 2005) when it was expected that there would be more groundwater present in the aquifers due to recent recharge from rainwater.

The groundwater quality sample reported in December 2004 also raised concerns with respect to hexavalent chromium, as the total chromium concentration reported appeared to indicate that the hexavalent chromium concentration could be higher than acceptable WHO guideline limits.

The results of the additional groundwater quality sampling study are presented in this report.

2. Scope of Work

The scope of work for the groundwater quality sampling study included:

- Sampling of groundwater after aquifer testing on the test pumping boreholes
- Data analysis
- Reporting

3. Methodology

The positions of the boreholes sampled are shown in Figure 1.

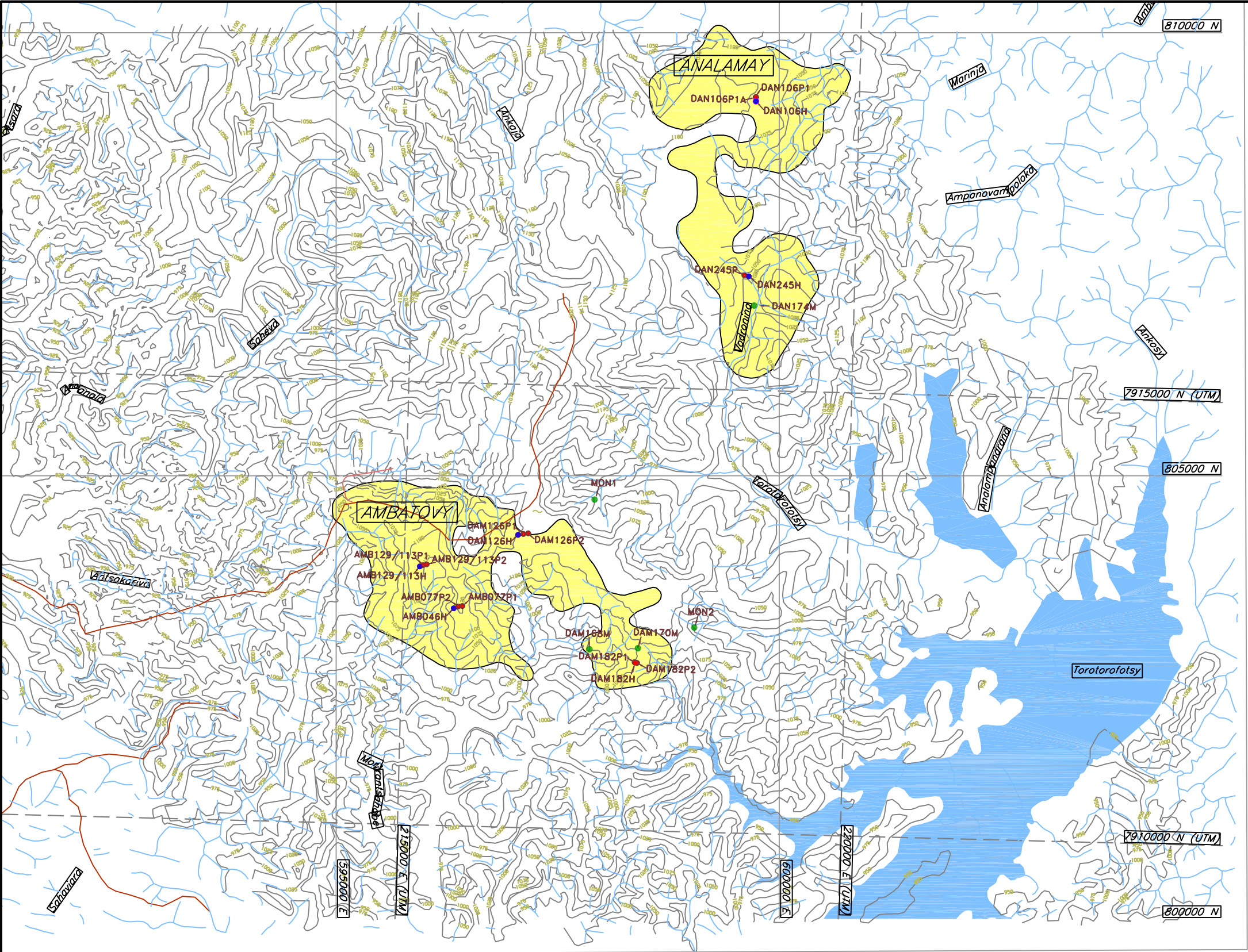
Grab samples were taken at boreholes DAN245H, DAM126H and the Korean Pit (locality unknown) on 26 and 27 March 2005. Samples were taken at the end of aquifer tests on the boreholes DAN245H, DAN106H, DAM126H, AMB046H and AMB129H/113H between 19 April and 28 April 2005.

Most samples were submitted for duplicate analysis, to Inspectorate M&L (Pty) Ltd in Johannesburg and either the Dynatec Laboratory in Fort Saskatchewan or JIRAMA Laboratory in Antananarivo (see Table 1).

4. Results

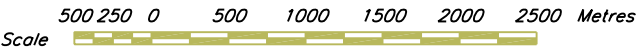
The results of all the samples taken are presented in Table 1, and where applicable, they have been plotted on a Piper diagram in Figure 2.

The groundwater samples are all Magnesium-Bicarbonate Type waters, which is indicative of recent recharge from infiltrating rainfall, as well as rock-water interaction with the magnesium-rich soil and rock horizons underlying the site.




LEGEND:

- Water/Wetland
- Orebody
- River/Stream
- Road
- Test pumping boreholes and piezometers
- Monitoring boreholes
- Groundwater sampling boreholes



NOTES:

- Topography and hydrology features provided by Golder Associates.
- Elevations shown are metres above sea level
- Grid is Laborde system with UTM overlay
- CAD drawing provided by Knight Piesold Consulting



WATER, ENVIRONMENTAL & EARTH SCIENCE CONSULTANTS

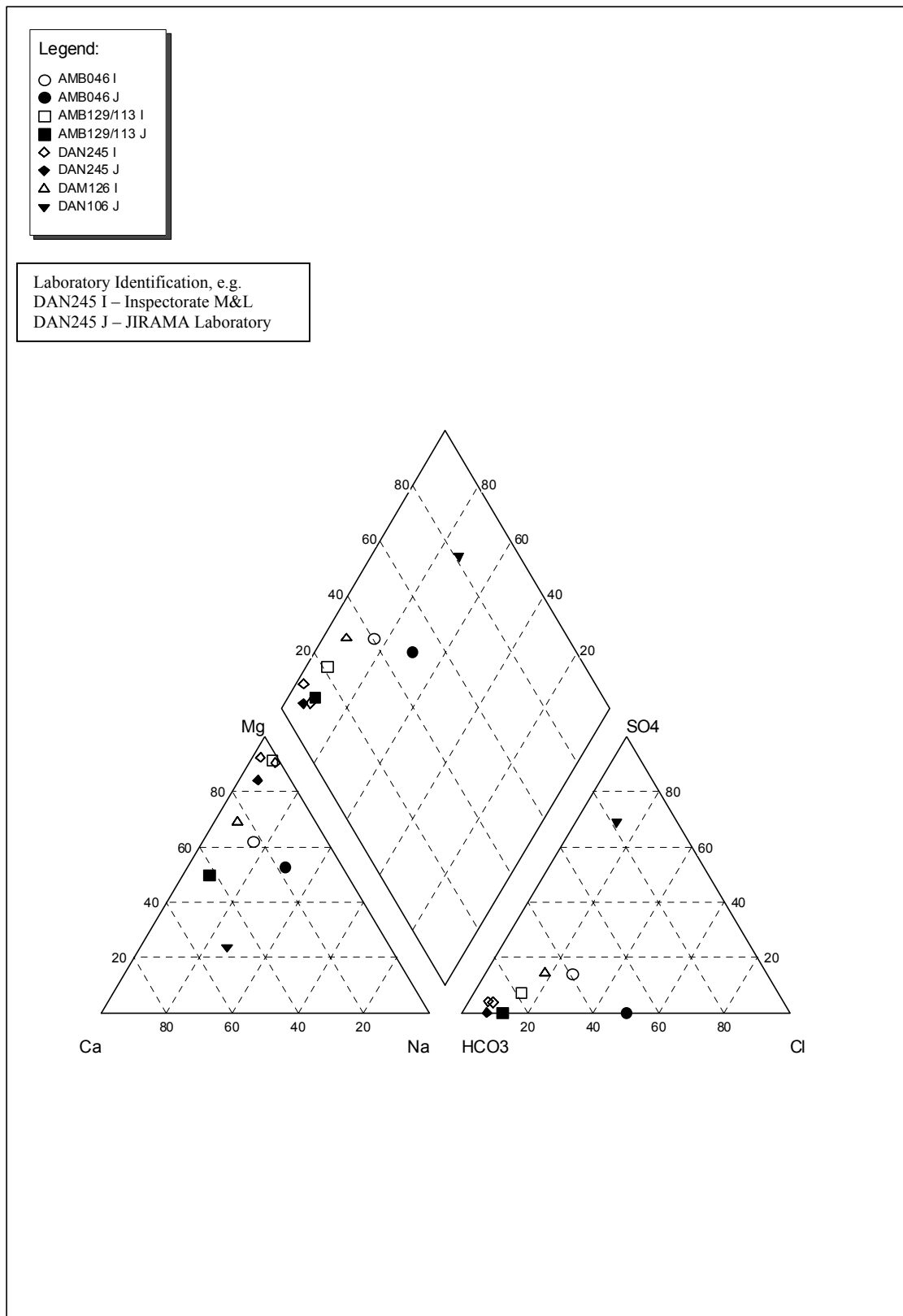
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CLIENT: Dynatec Metallurgical Technologies		BY	DATE
	DESIGNED	KPC	XXX
DRAWING TITLE: AMBATOVY & ANALAMAY MINING PROJECT GROUNDWATER SAMPLING POSITIONS	DRAWN	GS	09/06/05
	CHECKED	GS	09/06/05
	SCALE 1:50 000		
	DRAWING No. 1		REVISION 1

Table 1: Groundwater Quality Analysis Results

Borehole ID.			DAN245H					DAM126H				Korean Pit	AMB046H			AMB129H/113H		DAN106H
Sample Date			2004/07/31	2005/03/26	2005/03/26	2005/04/19	2005/04/19	2005/03/27	2005/03/27	2005/04/20	2005/04/20	2005/03/26	2005/04/21	2005/04/21	2005/04/21	2005/04/28	2005/04/27	
Laboratory				Inspectorate M&L	Dynatec	Inspectorate M&L	JIRAMA	Inspectorate M&L	Dynatec	Inspectorate M&L	JIRAMA	Inspectorate M&L	Inspectorate M&L	JIRAMA	Inspectorate M&L	JIRAMA	JIRAMA	
Comments				Duplicate, Cr(VI) sample acidified	Duplicate, Cr(VI) sample acidified	Duplicate	Duplicate, Cr(VI) sample not acidified	Duplicate, Cr(VI) samples acidified	Duplicate, Cr(VI) samples acidified	Duplicate	Duplicate, Cr(VI) sample not acidified		Duplicate	Duplicate, Cr(VI) sample not acidified				
Determinands and Units	pH EC TDS Hardness	mS/m	7.8			7.8				6.4			5.3		6.6	6.34	6.39	
		mg/l	15.8			13.6				6.02			3.36		11.0	7.05	12.97	
		mg/l	190			82				44			20		80			
		mg/l CaCO ₃	57			56				23			8.4		43			
	Ca Mg Na K	mg/l Ca	0.4			1.2	3.6			2.4			0.9	1.2	0.4	10.8	3.6	
		mg/l Mg	13.5			12.8	18.23			4.2			1.5	2.19	10.2	7.78	21.14	
		mg/l Na	2.2			0.6	2.3			0.8			0.7	2.3	1.3	2.3	2.3	
		mg/l K	<0.1			<0.1				0.1			0.5		0.2			
	Alkalinity HCO ₃ Cl SO ₄	mg/l CaCO ₃	56			52				16			8		32			
		mg/l HCO ₃	68			63	74.42			20			10	6.1	39	43.92	40.26	
		mg/l Cl	2.6			3.1	3.55			3.1			2.6	3.55	4.1	3.55	3.55	
		mg/l SO ₄	2.4			2.1	0.00			3.4			1.9	0.00	2.9	0.00	52.36	
	Cations Anions	meq/l	1.23			1.14	1.78			0.50			0.21	0.34	0.92	1.28	2.02	
		meq/l	1.24			1.16	1.32			0.49			0.28	0.20	0.82	0.82	1.85	
	Ag As Cr Cr (VI) Cu Fe Hg Mn Ni Se Si Zn	mg/l Ag	<0.004			<0.004				<0.004			<0.004		<0.004			
		mg/l As	0.06			<0.02				<0.02			<0.02		<0.02			
		mg/l Cr	0.13	0.32	0.286	0.10		0.19	0.098	0.29		<0.01	0.06		0.05			
		mg/l Cr		0.22	0.183		0.08	0.06	0.098		0.22	<0.01		0.06		0.014	0.065	
		mg/l Cu	<0.002			<0.002				0.002			<0.002		<0.002			
		mg/l Fe	0.08			0.12				0.17			0.06		0.74	10	0.3	
		mg/l Hg	<0.001			<0.001				<0.001			<0.001		<0.001			
		mg/l Mn	0.005			<0.001				0.02			0.10		0.22	0.00	0.76	
		Mg/l Ni		0.05		0.07		0.12		0.32		<0.003	0.10		0.74			
		mg/l Se	0.02			<0.03				<0.03			<0.03		<0.03			
		mg/l Si	19.3			15.6				6.89			1.0		13.9			
		mg/l Zn	<0.005			0.18				0.16			0.02		0.15			
	NO ₃ NO ₃ NO ₂	mg/l NO ₃				0.7	0.00			0.3			4.4	0.48	2.8	0.04	0.03	
		mg/l N	0.6			0.2				<0.1			1.0		0.6			
		mg/l NO ₂	<0.1			<0.1				<0.1			<0.1		<0.1			
	B F PO ₄	mg/l B	0.03			<0.006				<0.006			<0.006		<0.006			
		mg/l F	<0.1			<0.1				0.2			<0.1		<0.1			
		mg/l P	0.6			<0.1				0.1			0.2		1.5			

Figure 2: Piper Diagram of Groundwater Analyses



4.1. JIRAMA Laboratory Results

Due to inconsistencies in the JIRAMA analytical results, those results should be disregarded in the context of this investigation.

4.2. Hexavalent Chromium Analyses

The report issued by GCS in December 2004 contained one groundwater quality analysis for groundwater sampled from DAN245H on 31 July 2004 (see Table 1). The total chromium analysis for this sample gave a concentration of 0.13mg/l. The question was raised that a portion of this chromium could be in the toxic hexavalent state (Cr^{6+}). The WHO provisional guideline for drinking water for total chromium is 0.05mg/l.

Grab samples were collected on 27 and 28 March 2005 from DAN245H and DAM126H. These samples were preserved with acid, and analysed some weeks after the sample collection date. Duplicate samples were analysed at Inspectorate M&L and at the Dynatec Laboratory in Canada. The analyses revealed high concentrations of Cr^{6+} (see Table 1).

However, USEPA standards for the analysis of Cr^{6+} require that the water sample is not acidified, and that the analysis is conducted within 24 hours after sampling. Consequently, during the sampling undertaken in April 2005, dedicated samples were collected at the mine site and sent to the JIRAMA Laboratory for Cr^{6+} analysis. The results of these analyses reveal Cr^{6+} concentrations of between 0.06 mg/l to 0.22 mg/l (see Table 1), all of which are higher than the WHO provisional guideline of 0.05 mg/l for total chromium. This guideline is provisional due to the acknowledged difficulties of analysing for Cr^{6+} only¹.

It is probable that the results from the JIRAMA analysis of Cr^{6+} are also unreliable, in line with the discussion of the results in section 4.1. However, it is clear that there is a relatively high concentration of total chromium in the groundwater (see Table 1). The highest concentration measured is 0.32 mg/l. The presence of the chromium can be attributed to the natural occurrence of chromium in the ultramafic lithologies underlying the site and the weathered saprolitic and lateritic horizons derived from them.

Chromium occurs naturally almost exclusively in its trivalent state (Cr^{3+})². Chromium concentration in igneous rocks is positively correlated with the concentrations of silica, magnesium and nickel.

The occurrence of Cr^{6+} in the environment or groundwater is normally attributed to industrial activity, such as refractories and the like. Nevertheless, Cr^{6+} is known to occur naturally as well (e.g. Gray, 2003, GRAC)^{3, 4}. The mechanism for its occurrence is apparently not fully understood, but a popular hypothesis is that manganese oxides in the soil can act as oxidising agents to oxidise Cr^{3+} to Cr^{6+} (McBride, 1994)⁵.

¹ WHO (2003) *Chromium in drinking-water. Background document for the preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organisation (WHO/SDE/WSH/03.04/4)

² International Programme On Chemical Safety, Environmental Health Criteria 61 Chromium (1998). Geneva, World Health Organisation (EHC 61, <http://www.inchem.org/documents/ehc/ehc/ehc61.htm>)

³ Gray D. (2003) *Naturally occurring Cr6+ in shallow groundwaters of the Yilgarn Craton, Western Australia*. Geochemistry: Exploration, Environment, Analysis, 2003, vol. 3, no. 4, pp. 359-368(10)

⁴ Groundwater Resources Association of California (GRAC) <http://www.grac.org/ChromiumWhitePaper.pdf>

⁵ McBride M. (1994) *Environmental chemistry of soils*. Oxford University Press Inc., Oxford. 406 pp.

4.3. Nickel Analyses

Samples submitted to Inspectorate M&L were analysed for nickel concentrations in late June 2005. These analyses show that elevated nickel concentrations exist in particular in groundwater sampled from DAM126H and AMB129H/113H on 20 and 21 April 2005 (0.32mg/l and 0.74mg/l respectively). All the other analyses, except that for the Korean Pit, showed concentrations above 0.02mg/l, which is the WHO provisional guideline for drinking-water quality.

It can be noted however, that internationally, guidelines for nickel are not consistent. For example, the U.S. E.P.A. maximum level for drinking water is given as 0.1mg/l, whereas nickel is not included in the Canadian Drinking Water Quality Guidelines, although a guideline level for nickel is in preparation.

5. Conclusions

The groundwater samples indicate that the water is a Magnesium-Bicarbonate Type water, indicative of recent recharge by rainfall and natural rock-water interaction.

There is clear evidence of total chromium concentrations above the WHO provisional guideline for drinking-water quality of 0.05mg/l. The contribution of hexavalent chromium to this total concentration is not conclusively determined.

Nickel concentrations in the groundwater are elevated, and all groundwater samples had nickel concentrations above the WHO provisional guideline for drinking-water quality of 0.02mg/l.

6. Recommendations

Groundwater sampling should continue on a quarterly or biannual basis in order to establish a database of groundwater quality before mining activities commence on the site.

The presence or absence of hexavalent chromium in the groundwater should be conclusively determined. There are definite constraints on the potential for acquiring reliable analytical results. However, one possibility to achieve this aim could be to purchase field-testing equipment, e.g. the Hach Pocket Colorimeter II Kit (Chromium-Hexavalent, Diphenylcarbazide, 5870017

<http://www.hach.com>). which meets the U.S. E.P.A. method requirements and may be used for wastewater compliance monitoring.

APPENDIX A:

GROUNDWATER CHEMISTRY ANALYSIS CERTIFICATES

VOLUME I

APPENDIX 7.1

ATTACHMENT 3

**TAILINGS STORAGE FACILITY
ENVIRONMENTAL ASSESSMENT
HYDROGEOLOGICAL STUDY**

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**AMBATOVY NICKEL PROJECT - TAILINGS STORAGE FACILITY ENVIRONMENTAL
ASSESSMENT,
HYDROGEOLOGICAL STUDY**

for

Knight Piésold Ltd

**Report 04.01.040 4
October 2005**

Executive summary

GCS (Pty) Ltd. completed hydrogeological investigations for the Ambatovy Project tailings storage facility. The main aims of the hydrogeological investigation were as follows:

- To determine the characteristics of the pre-tailings disposal groundwater regime (baseline hydrogeology)
- To quantify potential impacts on the groundwater regime as a result of possible artificial recharge of seepage from the tailings dam (production phase and long-term)

BASELINE HYDROGEOLOGY

The field study was conducted between April 27 and June 30, 2004. The purpose of the investigation was to obtain site-specific groundwater data, which could be used to characterize the hydrogeology of the area.

Aquifer

The groundwater investigation focused on the main upper aquifer system situated less than 50 m below ground level. Deeper aquifers are less important in terms of the environment (for example base flow), potential future use (not economic in terms of rural abstraction) and vulnerability (less vulnerable). Three aquifer zones (hydrogeological units) were identified as follows:

- Upper Weathered Zone (inter-granular rock or residual soil). This zone consists mainly of decomposed gneiss and/or dolerite (residual soil). The average depth of this zone is 13 m. It has a lower hydraulic conductivity compared to the other zones, namely 0.31m/day (4×10^{-4} cm/s).
- Intermediate Weathered and Fractured Zone (partially weathered rock). The zone has double porosity flow characteristics, with fractures contributing to most of the groundwater flow. The average thickness of this zone is around 8 m. The permeability of the Inter weathered and fractured zone based on aquifer testing results is estimated to be 0.99 m/day (1.1×10^{-3} cm/s).
- Lower Fresh Rock Fractured Zone. The Lower Fractured Zone consists mainly of fractures in unweathered rock. The number of open fractures normally decreases with depth. Most fractures (frequency and open void area) are likely to be intercepted in the upper 20 m of the unweathered unit. More drilling is required to confirm this. The permeability of the Lower Fractured Zone is estimated to be 1.09 m/day (1.3×10^{-3} cm/s) based on aquifer testing results.

Groundwater Levels

Water level measurements were recorded in monitoring wells installed in the geotechnical and hydrogeological drillholes in June 2004. The observed depth to groundwater within the study area varies between 2 and 15 m below ground level. Groundwater gradients, in general, mimic the topographic surface and flow patterns are overall towards the east. The average groundwater gradient is between 1% and 2.5%.

Groundwater Quality

Groundwater samples were taken from boreholes HG1, HG2, HG3, HG5 and HG6 in the vicinity of the proposed Option 4 Tailings Dam (Figure 1). The groundwater quality of the area is in general suitable for domestic use (including human intake) according to the World Health Organisation drinking water guidelines. Elevated metal concentrations (compared to WHO standards) have been

analysed in samples from boreholes HG3 and HG5. Metals that exceed WHO standards are aluminium and zinc.

Based on the sample results, groundwater in the proposed tailings disposal facility area could be subdivided into either Mg, Ca, Na – HCO₃ or Na – HCO₃ dominant water

Groundwater use

Groundwater within the vicinity of the proposed tailing storage facility is utilised mainly via springs/seeps. Only one hand dug well has been identified within the TSF footprint area. No motorised or mechanical abstraction boreholes have been identified within the immediate vicinity of the TSF.

SEEPAGE ANALYSES

The proposed tailings storage facility will be developed in three phases in a valley and will cover three sub-catchments. Surface run-off and supernatant water will be decanted from the tailings basins into water basins from where the water will be reused.

Two dimensional seepage analyses were conducted utilising finite element software to estimate the potential seepage volumes to the groundwater. Various scenarios during the life of the tailings storage facility were modelled. The tailings basins were analysed for operating conditions as well as post closure conditions. The water basins were analysed with and without a synthetic liner system up to the normal operating water level.

Tailings deposition into the tailings basin will be done in such a manner as to blanket the tailings basin bottom with low permeability tailings to minimize supernatant seepage into the foundations. The predicted seepage losses from the tailings basins during the operational phase are expected to vary between 160 m³/day to 420 m³/day. The seepage volumes would not reduce significantly after closure due to the low permeability of the tailings and high regional rainfall and are expected to range between 300 m³/day and 50 m³/day approximately 100 years after closure.

It is proposed that the water basins would be lined to accommodate the normal operating water i.e. no seepage losses from the water basins during normal operating conditions. However, seepage losses of between 1000 m³/day and 4400 m³/day are expected during large storm events.

Tailings seepage quality

Leach and acid-base accounting tests (ABA) were conducted on representative tailings samples.

Laboratory drained settling tests indicate that the slurry water quality is likely to be sulphate (2500 mg/l), magnesium (2050 mg/l), calcium (450 mg/l) and manganese (230 mg/l) dominant. Other constituents have relatively low concentrations. Tailings seepage qualities during the production and decommissioning phases will be similar.

The ABA tests results indicate that it is not likely that acid leachate will emanate from the tailings material. The Net Neutralisation Potential (NNP = NP – AP) of the tailings sample is 8.3 kg CaCO₃ / tonne. Based on the AP:NP ratio (1:9.9) it can further be concluded that the tailings material is non acid forming.

Leachate qualities are likely to become better with time as salts are flushed out of the rehabilitated tailings areas. Calculations, based on the rate at which rainwater will replace tailings interstitial water, indicates that better quality seepage could be expected 10 to 16 years (average 15 years) after tailings disposal stops.

POTENTIAL GROUNDWATER IMPACTS AND MANAGEMENT OPTIONS

Groundwater quality

Production and decommissioning phase:

Tailings seepage infiltrating into the aquifer underlying the tailings and water basins will migrate towards groundwater discharge areas (streams and springs). The quantification of the potential impact of this tailings seepage was investigated by groundwater numerical modelling. Flow gradients and velocities were incorporated in a contaminant transport model in order to simulate the migration of soluble chemical constituents within aquifers.

Four scenarios were investigated to mitigate potential groundwater contamination, namely:

- *Scenario 1* No liner or drains (no mitigation measures).
- *Scenario 2* Drains below the tailings dam pool.
- *Scenario 3* Water basin lined with a synthetic liner.
- *Scenario 4* Water basin liner and interceptor boreholes. The term “interceptor boreholes” is used for the series of boreholes, which will be used to intercept the groundwater salt plumes migrating away from the proposed TSF. Interception will take place by lowering the surrounding groundwater level through abstraction, forming a drawdown capture zone.

Scenario 4 was chosen as the preferred mitigation measure. Stream water quality compliance with WHO drinking water guidelines were the main criteria in choosing and designing the preferred mitigation option. The number of abstraction boreholes varies between 16 and 32 for different tailings disposal phases. Abstraction rates would vary between 640 and 2000 m³/day.

The water basin liner and interceptor borehole system will limit groundwater contamination from the TSF footprint area. Interceptor borehole abstraction will continue after tailings disposal stops for another about 15 years. The tailings seepage quality is expected to improve after this period and interceptor borehole abstraction will be stopped.

Groundwater monitoring (quality and levels) will take place over this period and the data will be used to quantify and manage potential impacts.

Long-term:

Rainfall will become the main driving force of seepage from the tailings disposal facility once ore processing stops. Long-term tailings seepage quality is likely to become better within time. The seepage rate from the tailings facility will further decrease in the long-term compared to the production phase. The average seepage flux rate will be less than normal rainfall recharge.

The remnant salt plume will migrate in an easterly direction once interceptor borehole abstraction stops (up to 1000 m over 100 year period). Groundwater qualities in the long-term will mainly comply with WHO drinking water guidelines, except for manganese. Dilution from rainfall-runoff will, however, ensure that stream water quality (of all chemical constituents) complies with WHO guidelines.

Groundwater levels

Groundwater levels will be lowered as a result of interceptor borehole abstraction. The number of abstraction boreholes and abstraction rates were optimised to minimise the impact of groundwater drawdown. Groundwater drawdown cones will be limited to the direct catchment areas neighbouring the TSF. Water levels will start to recover once interceptor borehole abstraction stops.

Surface water quality – groundwater seepage

No significant deterioration in stream water quality is expected during the production and decommissioning phases as a result of groundwater seepage from the TSF area. A slight deterioration in stream water quality can be expected in the long-term when interceptor borehole abstraction stops and due to the migration of the remnant plume. Dilution within the streams will, however, ensure that quality complies with WHO drinking water guidelines.

Surface water flow – groundwater component

Groundwater abstraction from interceptor boreholes and the blanketing effect of the low permeability tailings material will reduce the groundwater baseflow component to stream flow. Reduction in the groundwater component during the production and decommissioning phases varies between 34 to 75% for drainage areas A1, B1, and C1 situated immediately down-gradient of the TSF. Long-term groundwater component reduction is $\pm 25\%$. The groundwater component to stream flow is, however, small compared to surface run-off.

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1 INTRODUCTION

1.1 GENERAL

GCS (Pty) Ltd were appointed by Knight Piésold Ltd to undertake a hydrogeological investigation for the proposed Ambatovy Nickel Project tailings storage facility. The Ambatovy Nickel Project involves mining of nickel and cobalt at Ambatovy and Analamay, Madagascar, some 130 kilometres to the east-northeast of the capital, Antananarivo. The project is jointly owned by Dynatec Corporation, Impala Platinum Holdings Limited (Implats) and Sumitomo Corporation.

Ore mined at the Ambatovy surface mine will be pumped as slurry to the Toamasina (Tamatave) ore processing plant over a distance of approximately 265 km to the northeast of the mine. The fines waste material produced during ore processing will be pumped onto a tailings storage facility. The proposed Ambatovy Nickel Project tailings storage facility (TSF) is to be situated 8 km to the west-southwest of Toamasina, near the Antanandave Village. Tailings disposal will cover the upper regions of three sub-catchments draining towards the Ambolona River, a total area of ± 1132 ha. Figure 1 shows the locality for the proposed site. The life of the facility is envisaged at 27 years and will consist of 3 disposal phases.

GCS completed the following reports for the hydrogeological investigation, namely:

- Ambatovy Project - Tailings Feasibility Design, Hydrogeologic Study Progress Report June 2004, Ref no.: Report 04.01.040 1.
- Ambatovy Project – Tailings Pre-Feasibility Design, Hydrogeological Study July 2004, Ref no.: Report 04.01.040 2.
- Ambatovy Project – Tailings Storage Facility Feasibility Design, Hydrogeological Study April 2005, Ref no.: Report 04.01.040 3.
- Ambatovy Project Tailings Storage Facility – Interceptor Borehole System September 2005 Ref no.: Report 04.01.040 Intercept.

This report combines all the above studies for the Environmental Assessment report. The main changes in tailings storage facility design, since 2004, include locality, deposition phases and water management mitigation measures. The final TSF design includes 3 depositional phases, namely: Phase 1- year 1 to 14, Phase 2 - year 15 to 20.5 and Phase 3 – year 20.5 to 27. The focus of proposed water management mitigation measures is to minimise the impact of tailings seepage on groundwater and surface water quality. Mitigation measures include a water basin liner and interceptor boreholes.

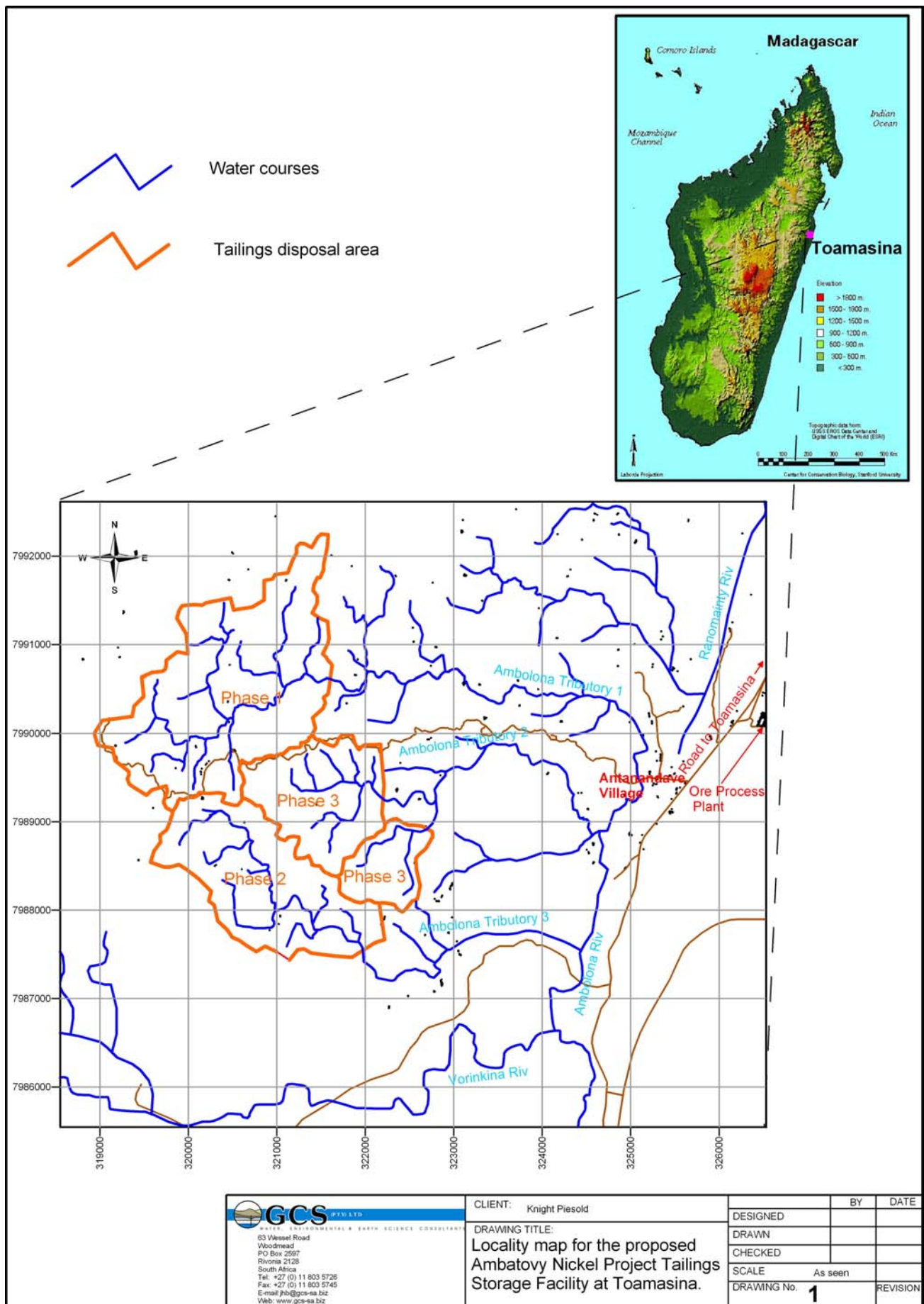
A detailed description of the hydrogeological study is provided below.

1.2 PROJECT AIM

The main aims of the hydrogeological investigation were to:

- Determine the characteristics of the pre-tailings storage facility groundwater regime (i.e. quality and quantity) – baseline study.
- Identify and quantify potential impacts on the groundwater regime, as a result of possible artificial recharge of poor quality seepage from the tailings dam (production phase, decommissioning phase and long-term).
- Investigate different water management mitigation options.

The results of the study would be used to update the Feasibility Study Environmental Assessment.



2 PHYSIOGRAPHY

2.1 TOPOGRAPHY AND SURFACE DRAINAGE

A series of valleys (generally west-east orientation), situated west of Toamasina make up the area of the planned tailings storage facility (TSF). The valleys are characterized by moderately steep, forested hillsides (valley walls), which descend into flat, wide valley floors. The topographic elevation at the tailings dam site varies between 5 mamsl and 110 mamsl.

The proposed tailings disposal area is situated within 3 river sub-catchments (Figure 3), namely:

- Tributary 1 of the Ambolona River (also referred to as Catchment A or TA-11 Catchment), flowing west to east over the northern sector of the proposed site.
- Tributary 2 of the Ambolona River (also referred to as Catchment B or TA-10 Catchment), draining most of the central sector of the proposed tailings dam site.
- Tributary 3 of the Ambolona River (also referred to as Catchment C or South Valley), draining the southern sector of the proposed tailings disposal area.

The Ambolona River flows in a southerly direction to the east of the proposed tailings dam and flows into the main watercourse of the area, namely the Ivondro River, which flows eastwards into the Indian Ocean.

2.2 CLIMATE

Madagascar's climate is a tropical maritime climate that is influenced by its altitude, the south-eastern trade winds, the monsoons, and its proximity to the sea.

The average annual precipitation for Toamasina area is in the order of 3300 mm. Figure 2 shows average monthly precipitation and A-pan evaporation data. The wettest months are January to March and the dryer months are September to October.

The average annual evaporation is in the order of 800 to 1000 mm. Precipitation exceeds evaporation for most of the year. Only during September and October does evaporation exceed precipitation.

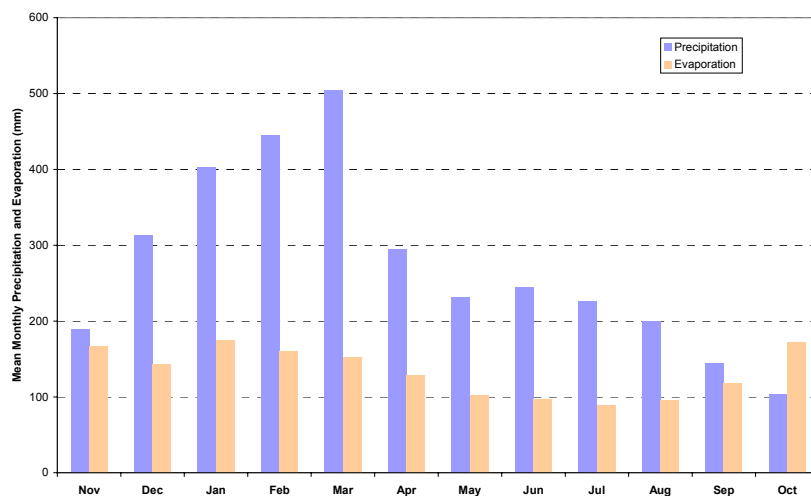
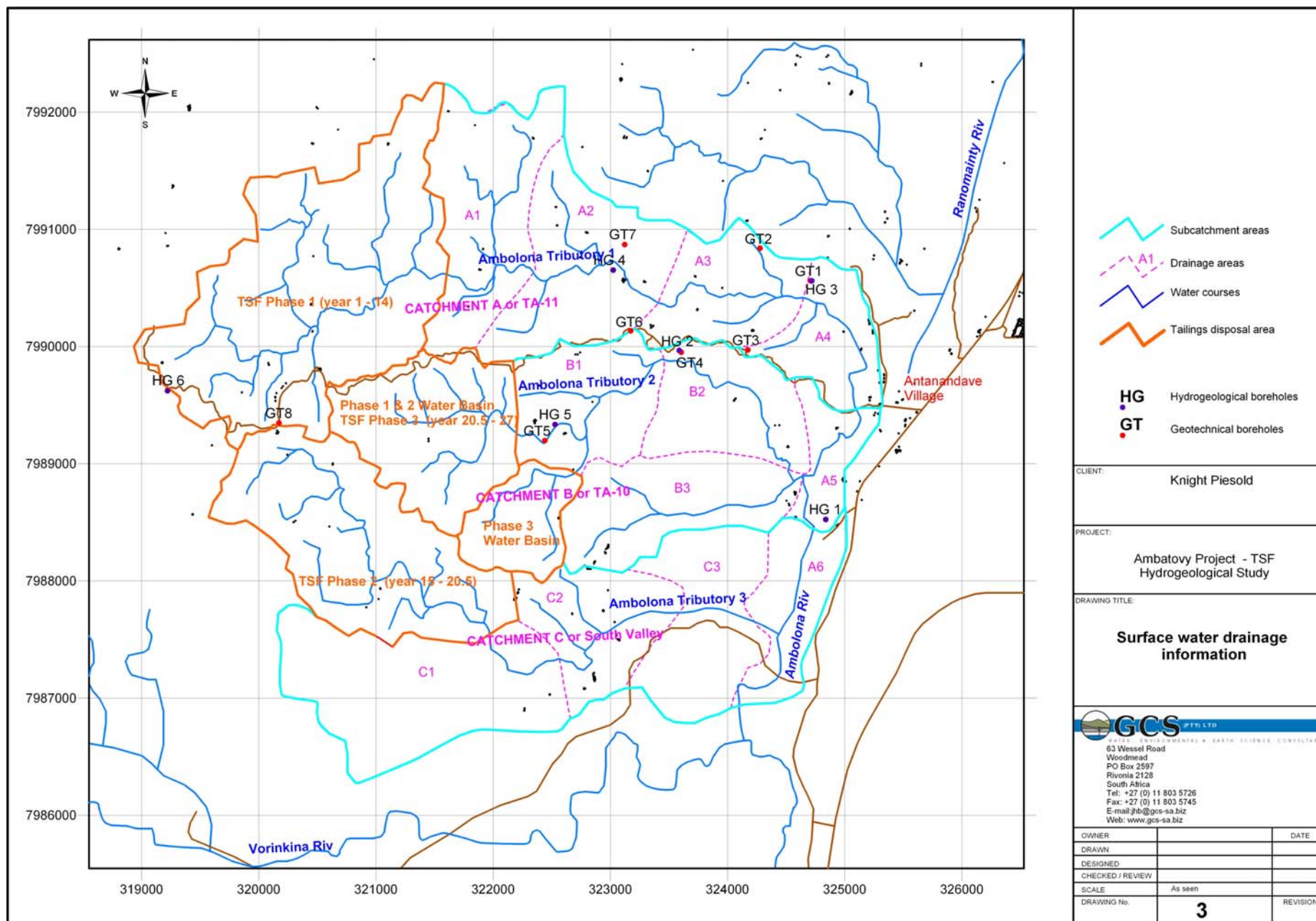


Figure 2: Mean monthly precipitation and evaporation values for Toamasina.



3 TAILINGS STORAGE FACILITY HYDROGEOLOGICAL STUDY

3.1 GROUNDWATER BASELINE DATA

3.1.1 Fieldwork

The field study was conducted between 27th of April and 30th of June 2004 and was done in conjunction with the geotechnical study of the proposed Tailings Storage Facility. It consisted of:

- Data compilation, analysis and verification.
- Conceptualising the area in terms of the geohydrology.
- Drilling of 6 monitoring boreholes in and around the tailings dam site.
- Performing aquifer testing.
- Obtaining groundwater quality samples.

The purpose of the investigation was to obtain site-specific groundwater data, which could be used to characterise the hydrogeology of the area.

A further 10 monitoring boreholes were drilled for the detailed design study during August to September 2005. These boreholes, however, do not form part of the EA study and will therefore not be discussed in detail for this report.

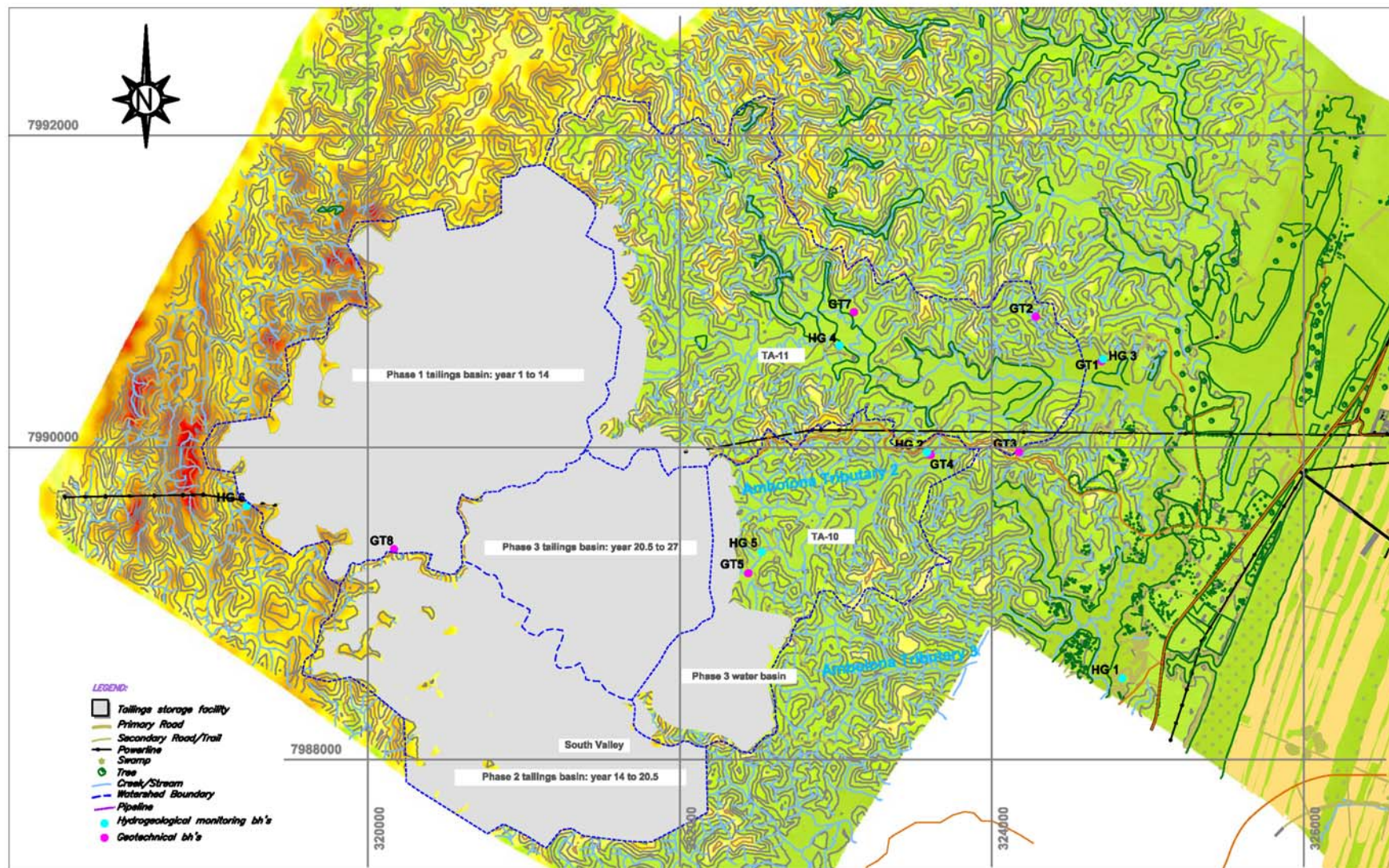
3.1.2 Monitoring boreholes

The majority of the data used to characterise the aquifer was obtained from the drilling and construction of the monitoring boreholes. Six groundwater monitoring boreholes (HG series) were drilled at the proposed tailings storage facility site in order to obtain groundwater levels, water quality data, geological data and aquifer parameters through aquifer testing. The positions of these boreholes are shown in Figure 4. Included in Figure 4 are the geotechnical borehole positions (GT series). Geological logs for the HG-series boreholes are presented in Appendix A.

The majority of the boreholes are located down-gradient of the Phase 1 basin, where disposal of tailings will take place for the first 14 years of operations. The siting process also took into account site accessibility, environmental aspects (for example wetlands or other sensitive landscapes), and social issues (for example crop areas).

Boreholes were drilled using a large diameter (165 mm) diamond core-drilling rig. Boreholes drilled for the groundwater study were constructed in order to remain open and act as monitoring boreholes. Construction details are given in Appendix A. Construction material included lockable cap and headworks, concrete plinth, steel starter casing, uPVC casing (solid and slotted) and gravel pack between the wall and casing. The chemically inert casing allows for the collection of representative groundwater samples.

Data from the geotechnical boreholes were used to supplement the groundwater borehole data. Most of the geotechnical holes were also equipped with slotted uPVC casing to act as piezometers.



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CLIENT: KNIGHT PIESOLD

DRAWING TITLE:

BOREHOLE POSITIONS

DESIGNED	BY	DATE
DRAWN		
CHECKED		
SCALE As seen		
DRAWING No. 4	REVISION 1	

3.1.3 Groundwater levels and flow gradients

Groundwater levels were obtained from:

- Groundwater monitoring boreholes drilled within and down-gradient of the proposed Tailings Storage Facility (*HG series*).
- Geotechnical boreholes (*GT series*).

The positions of these boreholes are shown in Figure 4. Groundwater level information is summarized in Table 1.

Table 1: Groundwater level data for the Option 4 Tailings Dam area – June 2004.

	Borehole ID	X co-ordinate	Y co-ordinate	Surface elevation	Borehole depth	Depth to groundwater level	Groundwater elevation
		UTM39	UTM39	mamsl	m	mbgl	mamsl
Hydrogeological	HG 1	324838	7988524	10.3	42	2.05	8.25
	HG 2	323588	7989966	21	30	5.55	15.45
	HG 3	324716	7990560	12.6	39.3	2.76	9.84
	HG 4	323024	7990652	31	36	13.5	17.5
	HG 5	322528	7989334	33	35	2.84	30.16
	HG 6	319221	7989622	67	41.7	13.77	53.23
Geotechnical	GT1	324708	7990561	9	33.86	2.68	6.32
	GT2	324277	7990839	20	36.32	4.95	15.05
	GT3	324173	7989971	28	20.52	14.87	13.13
	GT4	323605	7989951	10	21.5	4.9	5.1
	GT5	322441	7989197	13	16.85	2.6	10.4
	GT7	323122	7990870	20	16.31	11.93	8.07
	GT8	320172	7989348	46	25.59	10.5	35.5

mamsl - metres above mean sea level

m - meters

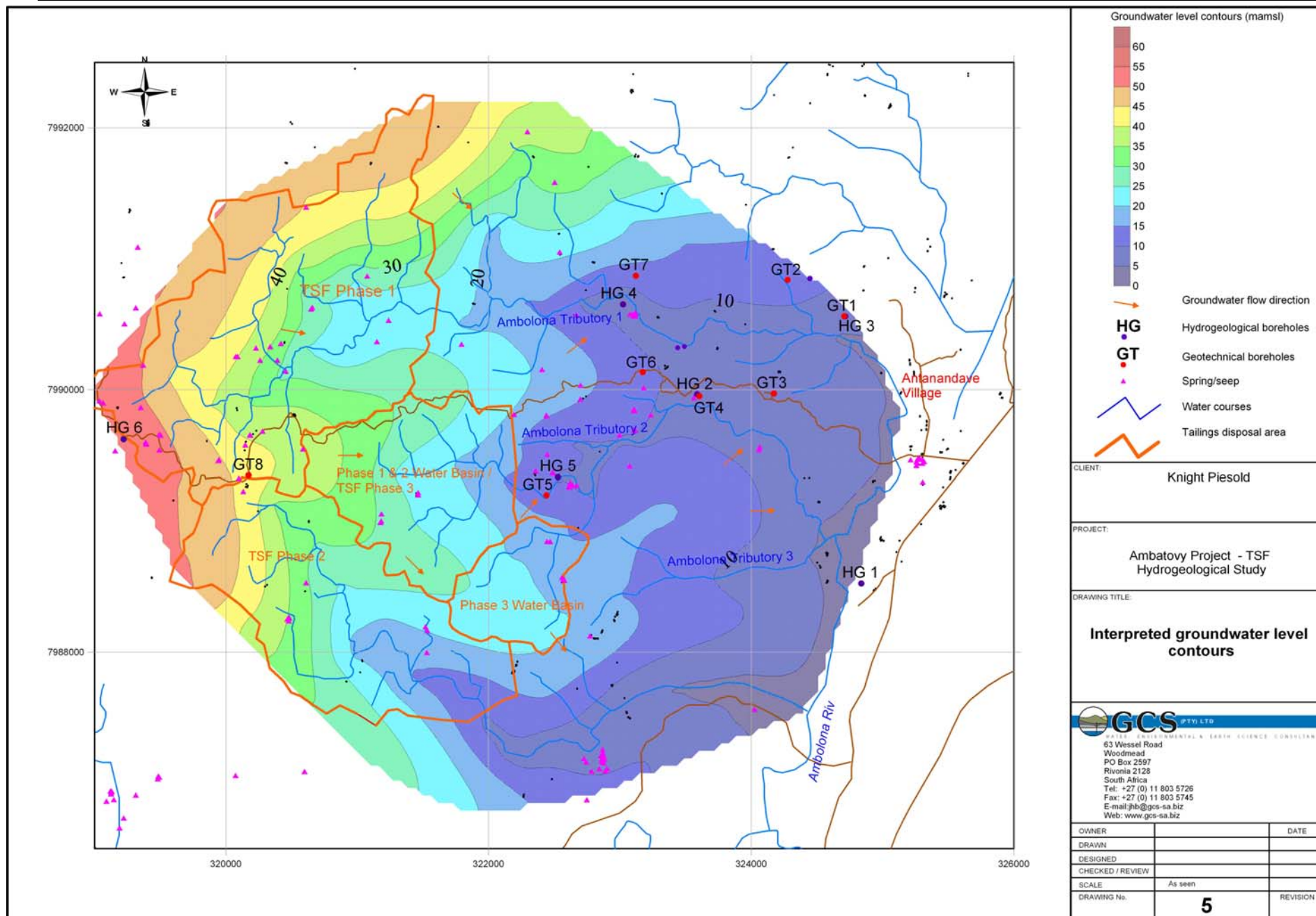
mbgl – metres below ground level

The observed depth to groundwater, within the study area, varies between 2 and 15 metres below ground level. Groundwater gradients in general mimic the topographic surface and flow patterns are overall towards the east. The average groundwater gradient is between 1% and 2.5%. The interpreted regional piezometric contours for the site are shown in Figure 5.

Groundwater contributes to surface water flow, mainly as base flow discharge in the river valleys. Evidence of groundwater day-lighting along the valley floors (discharge areas) includes the numerous wetland areas adjacent to streams. Identified springs/seeps (Figure 5) are mostly associated with watercourses. Groundwater discharge boundaries of concern include:

- Tributary 1 of the Ambolona River (Catchment A), Phase 1 Tailings Disposal catchment.
- Tributary 2 of the Ambolona River (Catchment B), Phase 1, 2 and 3 Water Basin and Phase 3 Tailings Disposal catchment
- Tributary 3 of the Ambolona River (Catchment C), Phase 2 Tailings Disposal catchment.

The calculated groundwater baseflow component at different stream sections is listed in Appendix B.



3.1.4 General aquifer description

The data associated with aquifers were obtained from the hydrogeological drilling programme. Other data used were water losses (drilling fluid) during drilling (indication of potential aquifers), aquifer test data, and geotechnical data (including packer tests).

The geology of the area consists of gneiss, containing biotite schist and migmatite lenses. Dolerite sills and dykes have intruded the older gneiss rocks. Dykes have a predominantly northeast-southwest to north-south strike direction. Dolerite sills and dykes are especially prominent along the central part (along the “spine road”) and northwestern part of the tailings dam area. Sills often form a capping above the gneiss. Dolerite is being mined in the northwest for aggregate stone.

Alluvium is found along streams and consists mainly of clayey silt material, formed by weathered gneiss & dolerite alluvium, washed from the higher areas. The thickness of this material is less than 2 metres in the vicinity of the proposed tailings dam. It therefore does not form an important hydrogeological unit. The thickness of the transported material increases slightly down-gradient along the valleys.

The groundwater investigation focussed on the main upper aquifer system situated less than 50 metres below ground level. Deeper aquifers are less important in terms of the environment (for example baseflow), potential future use (not economic in terms of rural abstraction) and vulnerability (less vulnerable).

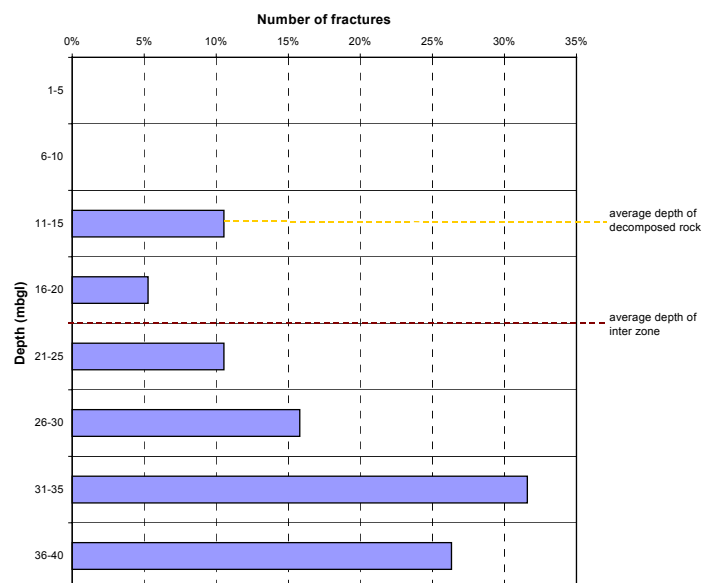
Three hydrogeological units were identified, namely:

- *An upper weathered intergranular rock unit.* This consists mainly of decomposed gneiss and/or dolerite. Table 2 shows the depth of this zone within the different boreholes. The average depth of this zone is 13 metres. It has a lower hydraulic conductivity compared to the other zones (Section 3.1.5) and is therefore not the most important unit in terms of groundwater flow. It contributes, however, to a large part of groundwater storage of the upper aquifer zone. This unit can form unconfined to leaky aquifers. In most cases, differences in rock weathering characteristics often result in variable permeabilities with depth and thus leaky aquifer conditions.
- *An intermediate zone, comprised of weathering and fracturing:* It has double porosity flow characteristics, with fractures contributing to most of the flow and both the inter-fracture matrix and the upper weathered zone contributing to storativity. Fractures are, however, often less open due to weathering and infill, compared to fracturing in the unweathered rock. Fractures are both horizontal and sub-vertical. The average thickness of this zone is around 8 metres (Table 2). It contributes to a large portion of the regional flow component:
 - It has a larger hydraulic conductivity compared to the weathered zone.
 - It is regionally more persistent compared to the lower fracture zones.
 - The vertical hydraulic conductivity between the intermediate zone and lower units is often relatively low, resulting in a less permeable base.
 - Aquifers are normally of a leaky nature.
- *Lower, fresh rock fractured unit:* The number of open fractures normally decreases with depth. Most fractures (frequency and open void area) are likely to be intercepted in the upper 20 metres of the unweathered unit. More drilling is required to confirm this. Figure 6 shows the fracture frequency with depth. The graph is, however, bias with increasing depth. This is due to the fact that fractures were less noticeable in the intermediate zone as a result of the drilling method (weak ore recovery and disturbance of core in the intermediate zone).

Fractures can either be as a result of structural deformation (tectonics) or on the contact of different lithologies (for example dolerite and the older gneiss rock). Fractures also appear to form more readily in the biotite schist.

Table 2: Depth and thickness distribution of the weathered and intermediate zone hydrogeological units for different boreholes.

Borehole ID	Borehole depth	Depth of base		Saturated thickness		Lithology
		Decomposed	Intermediate zone	Decomposed	Intermediate zone	
	<i>m</i>	<i>mbgl</i>	<i>mbgl</i>	<i>m</i>	<i>m</i>	
HG 1	42	11	14	8.95	5.05	gneiss-schist
HG 2	30	3	12	0	6.45	dolerite
HG 3	39.3	21	30	18.24	11.76	gneiss-schist
HG 4	36	11	25	0	11.5	gneiss-schist
HG 5	35	8	12	0	0	dolerite, gneiss
HG 6	41.7	18	30	4.23	12	gneiss-schist
GT1	33.86	23	32	20.32	11.68	gneiss-schist
GT2	36.32	24	28	19.05	8.95	dolerite
GT3	20.52	20	21	5.13	1	gneiss-schist
GT4	21.5	8	17	3.1	17	dolerite
GT5	16.85	3	13	0.4	13	dolerite, gneiss
GT6	19.9	14	18	No water level	No water level	gneiss-schist
GT7	16.31	9	11	0	0	gneiss-schist
GT8	25.59	13	22	2.5	9	gneiss-schist
Average		13	20	6	8	
95% confidence		-	-	5	3.5	

**Figure 6: Fractures observed with depth in monitoring boreholes.**

3.1.5 Aquifer parameters

3.1.5.1 Aquifer testing (hydraulic conductivity and transmissivity)

Packer testing

Double Packer testing was carried out in the following geotechnical boreholes, GT1, GT2, GT4, GT5 and GT7. The length of the “test section” was in most cases 2.0 m, with test sections varying from 1.5 m to 5.0 m in boreholes GT1, GT2 and GT4. Double Packer testing was used in order to obtain the hydraulic conductivity profile of the rock mass underlying the tailings dam. The method employed in each hole tested, consisted of five consecutive water (pump-in) tests, with each test lasting ten minutes, with a low-medium-peak-medium-low pressure sequence. The resulting data was analysed and the five lugeon values calculated as well as the respective permeability's for that specific test zone in m/day. The in-depth results of the lugeon and permeability can be found in Appendix C. Results of the data analysed are summarised in Table 3 below.

Table 3: Hydraulic conductivities, calculated from packer testing for different zones.

Borehole ID	Hydraulic conductivity		
	Decomposed	Intermediate zone	Un-weathered zone (fractured)
	m/day	m/day	m/day
GT1	0.11	0.03	-
GT2	-	0.12	0.17
GT4	-	1.44	1.01
GT5	-	1.20	2.67
GT7	0.51	2.14	0.51
Average	0.31	0.99	1.09

The gneiss and dolerite in the decomposed zone weathers to form either a silt or clay or a combination of both. This fine nature of the decomposed material accounts for the relatively low hydraulic conductivity of the decomposed zone.

The intermediate zone comprises a weathered and fractured zone, which increases the hydraulic conductivity of the rock mass. The fractures in the intermediate zone are possibly infilled with fine material which can decrease the permeability of the fractures.

The fractured unit occurs in a more competent rock mass, in terms of weathering. The gneiss tends to be more brittle due its crystalline nature and more fractures are common, with no significant weathering. Implications are that the fractures will be more open with no or minimal infilling and joint persistency been inversely proportional to the termination index, meaning the degree of joint persistence will be large, hence the higher hydraulic conductivity of the rock mass in the fractured zone.

Pumping tests

Pumping tests involved measurements of groundwater drawdown at a constant abstraction rate (Constant Discharge Tests) and measurement of the water level recovery with time (Recovery Tests). The duration of the constant discharge tests were between 11 and 19 hours at abstraction rates varying between 0.3 and 3 l/s (litre per second). Observation measurements in nearby boreholes (GT series boreholes <50metres away), showed little or no drawdown during the constant discharge testing. This could be due to intersection of different aquifers or the high storativities in valley floors.

The pumping test data is presented in Appendix D. A summary of results of these test are provided in Table 4. Transmissivity values were obtained by fitting Theis related analytical models.

Table 4: Summary of pumping test results.

Borehole ID	Borehole depth	Length of perforated casing	Transmissivities		Max drawdown	Abstraction rate	Lithology
			Constant Rate	Recovery			
	m	m	m ² /day	m ² /day	m	l/s	
HG 1	42	13.9	10.1	7.5	14.9	2.23	gneiss-schist
HG 2	30	16.7	5.47	5	15.8	2.8	dolerite
HG 3	39.3	8.7	3.89	5	22.8	3	gneiss-schist
HG 4	36	8.05	5.89	3	17	1.44	gneiss-schist
HG 5	35	14.1	1.01	0.7	26.9	0.94	gneiss-schist
HG 6	41.7	15	0.63	0.5	15.5	0.37	gneiss-schist
Average			4.5	3.61			

The averaged hydraulic conductivity value, calculated from transmissivity values is in the order of 0.5 m/day.

3.1.5.2 Other aquifer parameters

These parameters were obtained through studies in similar areas.

Aquifer storage

Storage for the area is likely to vary between 0.001 and 0.08, depending on the aquifer. Most aquifer storage is within the weathered zone (decomposed and intermediate zone units). Specific yield (unconfined) for the decomposed material can be as high as 8% (typical for silt). The confined storativity of the lower fractured zone is likely to be less, namely an order of 10^{-3} .

The groundwater storage for the Catchments A, B and C are in the order of 3×10^6 to 1×10^7 m³, based on:

Area = 18 km²

Thickness (decomposed + intermediate zone) = 15 m

Storage = 1 - 4%

Recharge

Site-specific rainfall recharge to groundwater for the area is not known. Recharge rates for similar areas (geology and rainfall) are in the order of 70 to 200 mm per annum. This equates to 2 to 7% of the mean annual rainfall.

3.1.6 Groundwater quality

Groundwater samples were taken from boreholes HG1, HG2, HG3, HG5 and HG6 in the vicinity of the proposed Option 4 Tailings Dam (Figure 3). All samples were taken after completion of aquifer testing in order to remove any drilling fluids. This ensures that representative samples are obtained. Samples were preserved and submitted to an accredited laboratory for analyses.

The hydrochemical data are provided in Table 5.

Water compliance to WHO standards

Chemical constituents that exceed the World Health Organisation (WHO) drinking water standards are highlighted in Table 5. The groundwater quality of the area is in general suitable for domestic use (including human intake). Elevated metal concentrations (compared to WHO standards) have been found in samples from boreholes HG3 and HG5. Metals that exceed WHO standards are:

- Aluminium (HG3) – often associated with particulate matter or organic complexes of high relative molecular mass. Aluminium occurs in groundwater as a result of leaching from soil and rock material. Biotite associated with the gneiss and schist also contains aluminium.
- Zinc (HG3 & HG5) - occurs in small amounts in almost all igneous rocks such as gneiss.

Table 5: Groundwater quality results for the proposed tailings dam area. – July 2004.

Constituent	Unit	WHO Domestic Water Standards	HG1	HG2	HG3	HG5	HG6
pH Value @ 19°C	pH	N/A	6.1	7.6	6.4	6.8	7.6
Conductivity @ 25°C	mg/l	N/A	15.2	24.9	11.8	21.8	30.6
Total Dissolved Solids	mS/m	0-1000	128	280	154	222	282
Calcium as Ca	mg/l	N/A	7.4	19.2	4.7	9.7	24
Magnesium as Mg	mg/l	N/A	2.1	13.8	<0.1	8.6	14.9
Sodium as Na	mg/l	0-200	13	11.7	12.9	22	17.6
Total Alkalinity as CaCO ₃	mg/l	N/A	34	108	42	82	126
Bicarbonate as HCO ₃	mg/l	N/A	41	132	51	100	154
Carbonate as CO ₃	mg/l	N/A	Nil	Nil	Nil	Nil	Nil
Chloride as Cl	mg/l	0-250	23	11.2	13.3	13.3	10.2
Sulphate as SO ₄	mg/l	0-250	1.9	2.9	1.4	3.5	3.8
Nitrate as NO ₃	mg/l	0-50	0.2	<0.1	<0.1	<0.1	<0.1
Nitrite as NO ₂	mg/l	0-3	<0.1	<0.1	<0.1	<0.1	<0.1
Fluoride as F	mg/l	0-1.5	-	-	-	<0.1	<0.1
Arsenic as As	mg/l	0-0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Aluminium as Al	mg/l	0-0.2	<0.01	<0.01	0.78	0.18	0.03
Nickel as Ni	mg/l	0-0.02	<0.003	<0.003	<0.003	<0.003	<0.003
Manganese as Mn	mg/l	0-0.5	0.11	0.03	0.02	0.13	0.27
Iron as Fe	mg/l	0-0.3	<0.001	<0.001	0.08	<0.001	<0.001
Vanadium as V	mg/l	N/A	<0.002	<0.002	0.002	<0.002	<0.002
Zinc as Zn	mg/l	0-3	1.13	0.22	8.1	9.1	2.10
Lead as Pb	mg/l	0-0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cobalt as Co	mg/l	N/A	<0.001	<0.001	<0.001	<0.001	<0.001
Copper as Cu	mg/l	0-2	<0.002	<0.002	<0.002	<0.002	<0.002
Chromium as Cr	mg/l	0-0.05	<0.003	<0.003	<0.003	<0.003	<0.003
Barium as Ba	mg/l	0-0.7	0.07	0.012	0.016	<0.001	0.02
Mercury as Hg	mg/l	0-0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Silica as SiO ₂	mg/l	N/A	26	73	63	47	75

txt

Exceed World Health Organisation drinking water standards

Characterisation of hydrochemistry

Hydrochemical plots used to characterise the water chemistry of the area are shown in:

- Figure 7 - Piper Diagram
- Figure 8 - Stiff Diagrams.

Groundwater in the proposed tailings dam area could be subdivided in the following types:

- HG1 – Mg, Ca, Na – HCO₃ dominant water.
- HG2 – Mg, Ca, Na – Cl, HCO₃ dominant water
- HG3 – Na – HCO₃ dominant water
- HG5 – Na, Mg (Ca) – HCO₃ dominant water
- HG6 – Mg, Ca (Na) – HCO₃ dominant water

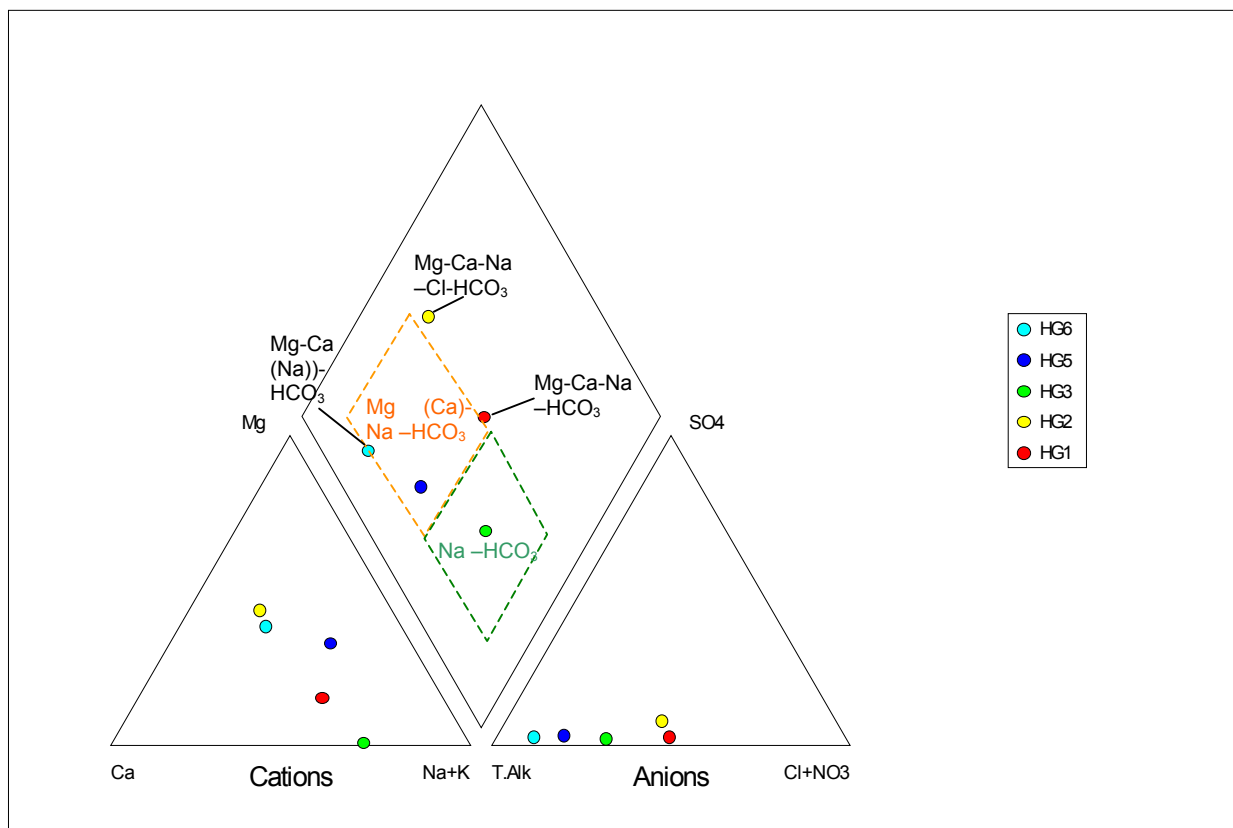


Figure 7: Piper diagram of groundwater samples in the vicinity of the proposed Option 4 Tailings Dam site.

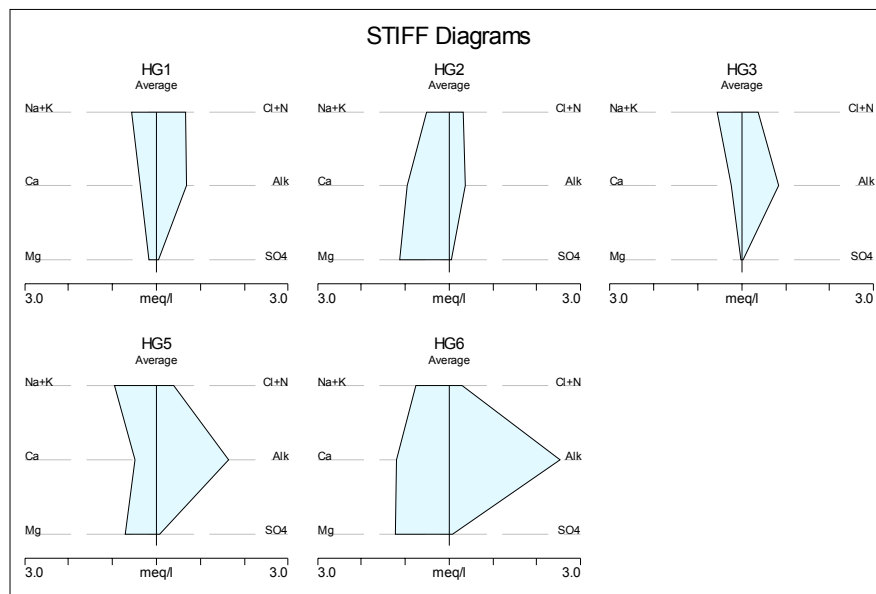
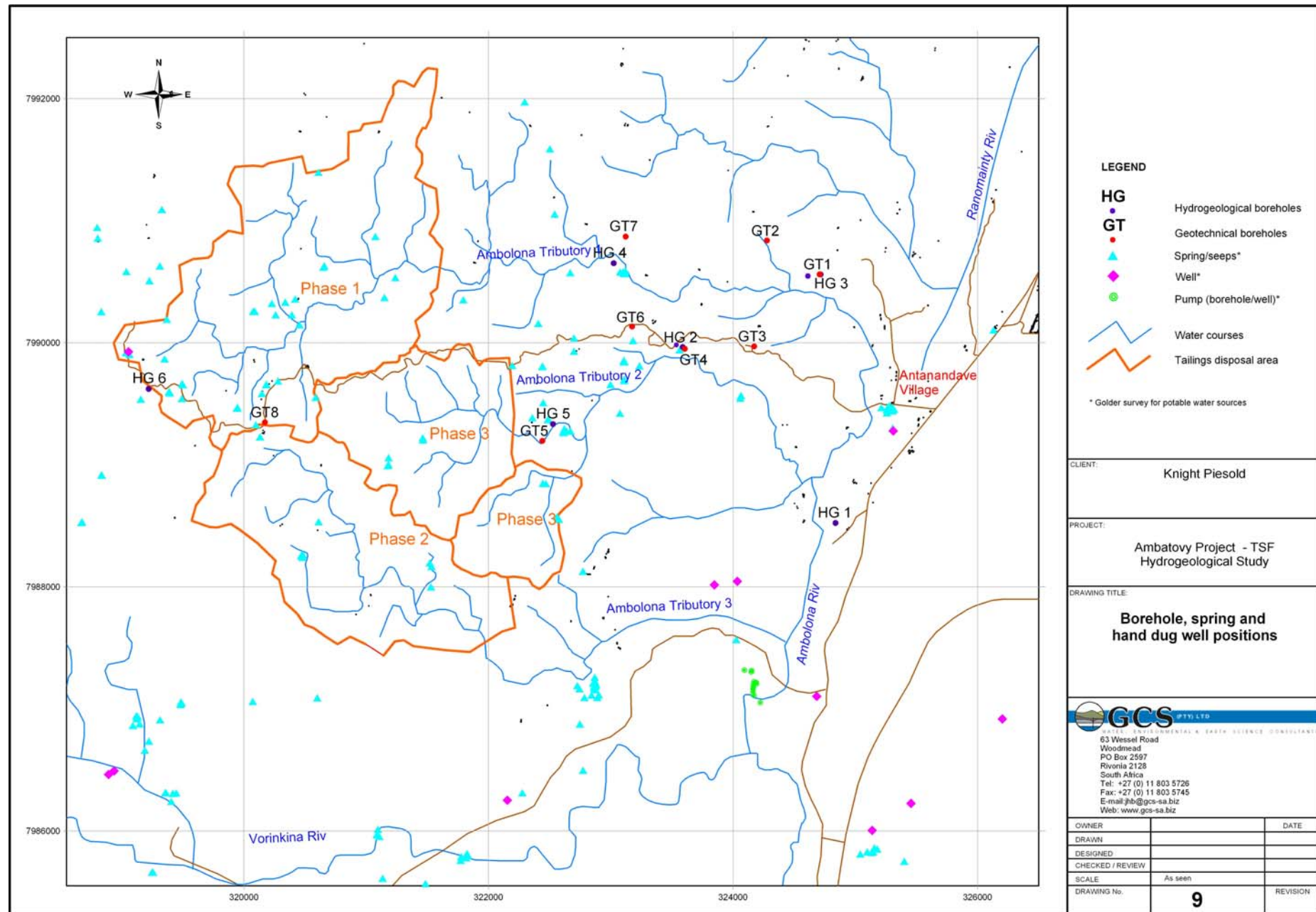


Figure 8: Stiff diagrams of groundwater samples in the vicinity of the proposed Option 4 Tailings Dam site.

3.1.7 Groundwater use

Groundwater within the vicinity of the proposed tailing storage facility is utilised for domestic purposes via springs/seeps and hand dug wells. No motorised or mechanical abstraction boreholes have been identified within the immediate vicinity of the tailings storage facility (TSF). Figure 9 shows the positions of springs and hand dug wells within the vicinity of the TSF. Only one hand dug well is situated within the TSF footprint area, namely in the western corner of the Phase 1 TSF. Springs/seeps are mostly along the valley bottoms, close to river channels.



3.2 TAILINGS SEEPAGE

3.2.1 Tailings storage facility seepage rate analysis

The proposed tailings storage facility is to be located in a valley and will cover three sub-catchments, refer to Figure E1, Appendix E. The total life of the tailings storage facility will be 27 years and will be constructed in three phases. The purpose of this seepage analysis is to evaluate the volume of seepage from the tailings basins and water basin facilities. Modelling was undertaken for Phase 1 to Phase 3 for the operational and post closure conditions.

The phases are described below:

- Phase 1 – Year 1 to 14 with a maximum outer embankment elevation to 80 mamsl.
- Phase 2 – Year 15 to 20.5 with a maximum outer embankment elevation to 65 mamsl.
- Phase 3 - Year 20.5 to 27 with a maximum outer embankment elevation to 72 mamsl.
- The tailings basin for Phase 3 will be used as a water basin during Phase 1 and 2.
- During Phase 3 a new water basin will be constructed to the southeast of the Phase 2 and 3 tailings basins.

3.2.1.1 Seepage modelling

3.2.1.1.1 Methodology

Two dimensional, steady state and transient state seepage analyses were conducted utilising the finite element software SEEP/W. The method is based on grid patterns, which divides the flow region into discrete elements. Material properties, such as permeability and volumetric water content, are specified for each element and boundary conditions (heads and flow rates) are set.

The operational conditions were simulated by a steady state analyses and the output information was utilized to perform a transient state analysis for closure conditions.

3.2.1.1.2 Model scenarios

The following scenarios were modelled for the tailings basins:

- End of Year 1
- End of Phase 1 – Year 14.
- End of Phase 2 – Year 20.5.
- End of Phase 3 – Year 27, including the HDPE liner up to elevation 28 mamsl and excluding the HDPE liner (this basin will be used as a water basin for Phase 1 & 2).
- Tailings basins Post Closure Phase 1,2 & 3.

The tailings basins were analysed at the final embankment and tailings elevation and with a pool depth of 1.5 m. Sections were analysed to obtain realistic seepage values that would be representative of the tailings basin (refer to Appendix E).

During the feasibility phase seepage analyses were conducted for Phase 1 including a scenario with under drainage systems to the tailings basin area. This scenario was not considered during this study due to the tailings characteristics that could cause possible blinding of the drains (as suggested by Knight Piesold in the Feasibility Report).

The water basins were analysed through the embankment and the ridges (refer to Appendix E).

Two scenarios were modelled for the water basins:

- No liner system to the basins allowing seepage to the foundation, modelling normal operational conditions with a mean water elevation 25 mamsl.
- A synthetic liner system to elevation 28 mamsl, modelling storm conditions with water level at elevation 36 mamsl. This scenario was modelled to simulate the seepage effect of short-term stormwater storage.

The pool area and beach areas used for the tailings basin are listed in Table 6 below.

Table 6: Tailings Basin Geometry

Phase	Life (years)	Pool Area (m ²)	Downstream Beach Area (m ²)	Upstream Beach Area (m ²)
Phase 1 Year 1	1	842,000	1,085,000	
End of Phase 1	1 to 14.	460,000	1,675,000	1,702,000
End of Phase 2	14 to 20.5	220,000	2,152,000	
End of Phase 3	20.5 to 27	200,000	1,515,000	
Phase 1 Post Closure	-	80,000	2,051,000	1,702,000
Phase 2 Post Closure	-	80,000	2,295,000	
Phase 3 Post Closure	-	80,000	1,635,000	

The mean pool areas used for the water basin are listed in Table 7 below:

Table 7: Water Basin Pool Size

Phase	Life (years)	Water Elevation (mamsl)	Mean Pool Area (m ²)
1 & 2 *	1 to 20.5	25	318, 000
1 & 2 **	1 to 20.5	36	663,000
3 *	20.5 to 27	25	263,000
3 **	20.5 to 27	36	400,000
* No liner installed to the water basin			
** Including a synthetic liner system up to elevation 28 mamsl			

3.2.1.1.3 Boundary conditions

The models were set up to determine the volume of seepage from the tailings basins and water basins. The supernatant ponds for the tailings basins were modeled using a constant head of 1.5m.

For the internal embankment drains a zero pressure head boundary was used. This condition assumes that the drains will always be free draining and will not have a buildup of positive pore-water pressures.

The rainfall conditions were simulated by applying a unit flux to the beach areas of 1% of the total rainfall volume over time.

3.2.1.1.4 Material parameters

Material properties of the tailings, embankments and the founding horizon for the tailings storage facility are summarised in Table 8 below:

Table 8: Material Properties

Material Type	Permeability	Data Source
Tailings (normally consolidated – un-drained)	1.0×10^{-8} m/s	Tailings slurry consolidation testing
Tailings (consolidated – drained)	1.0×10^{-9} m/s	Tailings slurry consolidation testing
Embankment	2.5×10^{-7} m/s	Geopractica permeability testing
Foundation	2.3×10^{-6} m/s	Packer testing

Results of the consolidation analyses (by Knight Piesold) indicate that very little consolidation will take place during the operating life of the facility.

3.2.1.2 *Model results*

A series of flux sections to measure seepage from the tailings basin and water basin were placed at the contact between the tailings/water and the foundation layer. The flow rates derived from the simulation were converted to calculate the total seepage volumes (refer to Appendix E).

The total seepage volumes for the tailings basin are summarised in Table 9 below:

Table 9: Summary of Seepage Volumes for Tailings Basin

Phase	Scenario	Pool (m ³ /day)	Down Stream Beach (m ³ /day)	Down Stream Beach (m ³ /day)	Total (m ³ /day)
1	Year 1	330	71		401
1	End of life	182	206	131	416
2	End of life	30	169		199
3	End of life – no liner	151	66		217
3	End of life – liner	100	60		160

The total seepage volumes for the water basin are summarised in Table 10 below:

Table 10: Summary of Seepage Volumes for Water Basin

Phase	Scenario	Under Drains (m ³ /day)	Groundwater (m ³ /day)	Total (m ³ /day)
1 & 2*	No liner system	650	769	1,419
1 & 2 **	Liner system, water level at 36m	1,000	3,392	4,391
3*	No liner system	220	852	1,072
3 **	Liner system, water level at 36m	120	3,328	3,448
* No liner installed to the water basin ** Water Basin at storm conditions				

The above table indicates the seepage volumes from the water basins with the exclusion of a liner system and during storm conditions. The objective of the water basin design is to install a liner system up to elevation 28mamsl to eliminate seepage losses during normal operating conditions.

Table 11: Summary of Seepage Volumes for Closure Stages of Tailings Basins

Phase	Time	Seepage volume (m ³ /day)
1	End of Life	519
1	60 year	475
1	100 year	335
2	End of Life	199
2	20 year	150
2	60 year	127
2	100 year	127
3 liner	End of Life	260
3 liner	20 year	242
3 liner	60 year	137
3 liner	100 year	47
3 no liner	End of Life	217
3 no liner	20 year	148
3 no liner	60 year	94
3 no liner	100 year	51

3.2.2 Tailings storage facility seepage quality

Tailings will be pumped from the plant area to the tailings storage facility area. The hydrochemistry of water used to pump the tailings will be altered, mainly due to the ore processing operation. Analysis of supernatant tailings water quality (slurry water), as analysed by laboratory drained settling tests, is given in Table 12.

Also provided in Table 12 is World Health Organisation (WHO) drinking water guidelines. Constituents that exceed these standards are highlighted, namely sulphate (SO₄) and manganese (Mn). Molybdenum (Mo) and nickel (Ni) marginally exceed the drinking water guidelines. Magnesium (Mg) and calcium (Ca) concentrations that have no specified target WHO guidelines are also elevated. Other constituents are relatively low and comply with drinking water standards. The pH of the water is neutral. Supernatant water can be described as Mg (Ca, Mn) – SO₄ dominant in terms of its hydrochemical characteristics.

Oxidation tests (peroxide oxidation), were performed as part of NAG testing (Net acid generation) and give an indication of the relative salt load that might go into solution after full oxidation of the tailings material. These tests gave similar chemical results to that of the above water soluble drained settling tests.

The main ore processing activities that impact on the slurry water quality include:

- Ore leaching with H₂SO₄ (sulphuric acid) increases the SO₄ concentration and lowers the pH. Mg and Mn are also mobilised from their naturally occurring oxidation phases within the ore rock.
- Tailings neutralisation with CaCO₃ (from limestone) increases the pH and Ca concentration. Some Mg and Mn is precipitated as hydroxides. Gypsum (CaSO₄·2H₂O) is also precipitated, decreasing the Ca and SO₄ concentrations slightly.

Table 12: Tailings water quality as per drained settling test.

Constituent	Units	WHO drinking guidelines	Slurry water
pH	pH units	NS	8
Conductivity	mS/m	NS	800
Total dissolved solids	mg/l	< 1000	6190
Total suspended solids	mg/l	NS	200
Calcium as Ca	mg/l	NS	450
Magnesium as Mg	mg/l	NS	2050
Sodium as Na	mg/l	< 200	50
Potassium as K	mg/l	NS	0.43
Alkalinity	mg/l as CaCO ₃	NS	87
Sulphate as SO ₄	mg/l	< 250	2491
Chloride as Cl	mg/l	< 250	12
Fluoride as F	mg/l	< 1.5	1
Nitrite as NO ₂	as N mg/l	< 3	< 0.06
Nitrate as NO ₃	as N mg/l	< 50	< 0.05
NH ₃ +NH ₄	as N mg/l	NS	0.1
Phosphate as PO ₄	mg/l	NS	< 10
Aluminium as Al	mg/l	NS	<0.003
Antimony as Sb	mg/l	< 0.02	<0.008
Barium as Ba	mg/l	< 0.7	0.005
Boron as B	mg/l	< 0.5	<0.005
Iron as Fe	mg/l	< 0.3	<0.003
Manganese as Mn	mg/l	< 0.5	230
Mercury as Hg	mg/l	< 0.1	<0.001
Molybdenum as Mo	mg/l	< 0.07	0.1
Arsenic as As	mg/l	< 0.01	<0.001
Chromium as Cr	mg/l	< 0.05	0.012
Cobalt as Co	mg/l	NS	0.06
Copper as Cu	mg/l	< 2	0.009
Nickel as Ni	mg/l	< 0.02	0.083
Lead as Pb	mg/l	NS	<0.005
Lithium as Li	mg/l	NS	<0.005
Scandium as Sc	mg/l	NS	10
Silica as Si	mg/l	NS	0.5
Selenium as Se	mg/l	< 0.01	<0.1
Tellurium as Te	mg/l	NS	<0.1
Vanadium as V	mg/l	NS	<0.002
Zinc as Zn	mg/l	NS	<0.002

txt	Exceed World Health Organisation drinking water guidelines
NS	Not specified

Acid-base accounting (ABA) tests were conducted on representative tailings samples (laboratory generated) in order to obtain the acid-base potential of tailings material. Results from the acid-base accounting testing are summarised in Table 13. The ABA tests results indicate that it is not likely that acid leachate will emanate from the tailings material. The net neutralisation potential (NNP = NP – AP) of the tailings sample is 8.3 kg CaCO₃ / tonne. Further, based on the AP:NP ratio (1:9.9) it can be concluded that the tailings material is non acid forming (Appendix F).

Table 13: Acid-base accounting test results.

Parameter	Unit	
Paste pH	pH units	7.52
NP	kg CaCO ₃ /tonne	9.75
AP	kg CaCO ₃ /tonne	1.56
NNP	kg CaCO ₃ /tonne	8.20
NP:AP	ratio	9.90
S	%	0.05
SO ₄	%	21.35
Final NAG pH	pH units	7.9
NAG	@pH4.5	<0.1
NAG	@pH7.0	<0.2

NP – Neutralising potential
 AP – Acid generation potential
 NNP – Net neutralising potential
 NAG – Net acid generation

The quality of leachate from the tailings dam would not be influenced by plant process activities once production ends, but by the tailings material itself. Salts will be washed out of the tailings material relatively quickly, resulting in decreasing concentrations with time. Leachate will be generated by rainwater falling onto the rehabilitated tailings. Clean rainwater infiltration will replace the tailings interstitial water at a rate of 2 to 4 metres per annum, based on rainwater infiltration velocities. The tailings material thickness varies between 33 to 50 metres for the different phases. Rainwater infiltration through the tailings storage facility will take between 10 and 16 years. The seepage from the tailings material, infiltrating the aquifer, is likely to increase substantially once the rainwater has infiltrated through the TSF, replacing interstitial water. This is based on the assumption that the tailings material is relatively inert and would not impact the infiltrating rainwater chemistry substantially. More geochemical waste characterisation data would be required to substantiate this.

3.3 POTENTIAL IMPACTS OF TAILINGS STORAGE FACILITY ON THE GROUNDWATER REGIME

Potential impacts on groundwater as a result of tailings disposal are discussed in terms of the TSF production phase, decommissioning phase and the long-term scenario.

3.3.1 Production phase

3.3.1.1 Groundwater quality

Methodology

Seepage infiltrating into the aquifer underlying the tailings basin will migrate towards groundwater discharge areas (streams and springs). A numerical groundwater flow model was used to study the potential impact of the tailings dam on the groundwater resources of the area.

Field data, such as groundwater gradients and hydraulic parameters, were used to construct and calibrate the groundwater flow model. Seepage flux rates, calculated for different localities and phases of the tailings storage facility (Section 3.2.1) were also incorporated into the model. A specified flux boundary (Neumann Condition), namely the recharge package, was used to simulate seepage through the unsaturated zone. The initial infiltration rate from the tailings storage facility will be relatively high (tailings disposal on natural ground), but will decrease as blanketing by the low permeability tailings takes place. This was simulated at each tailings disposal phase using a higher recharge flux rate for the first few years, decreasing towards the end of each phase.

Flow gradients and velocities were incorporated in a contaminant transport model in order to simulate the migration of soluble chemical constituents within aquifers. Chemical constituents modelled were total dissolved solids (TDS - measure of the amount of inorganic salts dissolved in water), sulphate and manganese. These parameters have been identified as the most relevant indicator chemical parameters for potential groundwater contamination at the TSF. Source quality (tailings seepage) is discussed in Section 3.2.2. Average ambient groundwater concentrations of the above chemical constituents are 200 mg/l TDS, 5 mg/l SO₄ and 0.1 mg/l Mn respectively.

A description of the groundwater model construction and calibration is given in Appendix G.

Scenario modelling

Four tailings seepage scenarios were investigated over the study period April 2004 to September 2005, namely:

- *Scenario 1* No liner or drains.
- *Scenario 2* Drains below the tailings dam pool.
- *Scenario 3* Water basin lined with a synthetic line.
- *Scenario 4* Water basin liner and interceptor boreholes.

Seepage and groundwater modelling were conducted and salt plumes (total dissolved solids, sulphate and manganese) were calculated for each scenario. Modelled salt plumes are presented in Appendix H. A summary of each scenario is provided below:

- *Scenario 1 No liner or drains.* Salt plumes migrate up to 1000 metres down-gradient of the TSF (boundary concentration value = 5 mg/l SO₄) over a 10 year modelled simulation period. Most seepage occurs from the water basin area, resulting in relatively high salt concentrations within the groundwater. Simulated sulphate and manganese groundwater plumes are presented in Appendix H1.

- **Scenario 2 Drains below the tailings dam pool.** The groundwater quality benefit from the Scenario 2 drains is insignificant compared to Scenario 1. This is due to the low permeability of the tailings material that makes the drains less effective once covered by tailings. The groundwater zone of impact in terms of quality, towards the end of Phase 1, will be similar to Scenario 1. Seepage from the water basin will also be high as in Scenario 1. Simulated salt plumes are presented in Appendix H2.
- **Scenario 3 Water basin lined with a synthetic liner.** Scenario 3 will reduce the lateral migration of soluble salts and the zone of impact significantly. With a liner covering the more permeable water basin foundation material, seepage is reduced from 769 m³/day to almost zero compared to that of the no liner scenario. Lining will consist of a synthetic liner up to an elevation of 28 mamsl. The capacity of the dam is such that no seepage is expected under normal weather conditions.

Simulated salt plumes for the three tailings disposal phases are presented in Appendix H3. Figures 1a - c, 2a - c and 3a - c (H3) show modelled salt plumes at the end of each tailings disposal phase (Phase 1- 3) for TDS, sulphate and manganese respectively.

- Salt plumes extend up to a distance of 500 metres away from the tailings dam (end of Phase 3 – 27 year period). The furthest groundwater salt plume migration will take place down-gradient of Phase 1 (Catchment A or TA-10 catchment area).
 - Lateral migration of salts will initially take place at a relatively high transport velocity, but will decrease as seepage volumes decrease. The low permeability tailings and lined water basin will blanket the natural soil and vertical fluxes to the underlying aquifer will become less than natural rainfall recharge with time. Groundwater gradients will therefore become smaller and flow velocities will decrease. This will limit the lateral migration of salt plumes.
 - The highest salt concentrations are below and down-gradient of the tailings ponds. This is due to the higher infiltration rate below these water bodies.
- **Scenario 4 Water basin liner and interceptor boreholes.** Figure 10 shows a schematic cross section through the TSF area and proposed interceptor borehole system (also referred to as pump-back and scavenger wells). The term “interceptor boreholes” are used for the series of boreholes, which will be used to intercept the groundwater salt plumes migrating away from the proposed TSF. Interception will take place by lowering the surrounding groundwater level through abstraction, forming a drawdown capture zone. Abstracted groundwater will be pumped back to the proposed lined water basin.

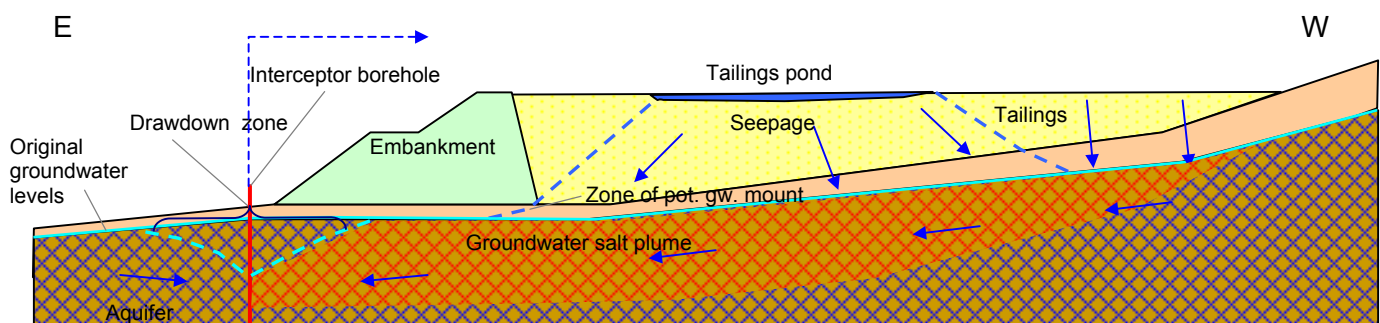


Figure 10: Schematic cross section of interceptor borehole system.

The number of boreholes and system arrangement were optimised using the existing groundwater model. The interceptor borehole system is discussed in more detail in Section 3.4. Groundwater salt plumes will be limited to the TSF footprint area (Appendix H4).

Groundwater quality impact

Groundwater quality, down-gradient from the TSF, and its impact on stream water quality were the main consideration in determining the final proposed mitigation measures. It was decided to adopt Scenario 4 (interceptor borehole system and water basin liner), which will limit the potential impact on groundwater to the TSF site. This will further ensure that downstream surface water qualities comply with WHO drinking water guidelines.

3.3.1.2 Groundwater levels

Groundwater levels will be lowered as a result of interceptor borehole abstraction (Scenario 4). Figure 11 shows the groundwater drawdown cone generated by the interceptor boreholes at the end of the production phase (year 27). The impact on groundwater levels is local, less than 1 km from the TSF. Abstraction was optimised to capture contamination with minimum pumping. The calculated interceptor borehole abstraction will vary from 640 to 1040 m³/day over the life of the TSF.

3.3.1.3 Surface water quality – groundwater seepage

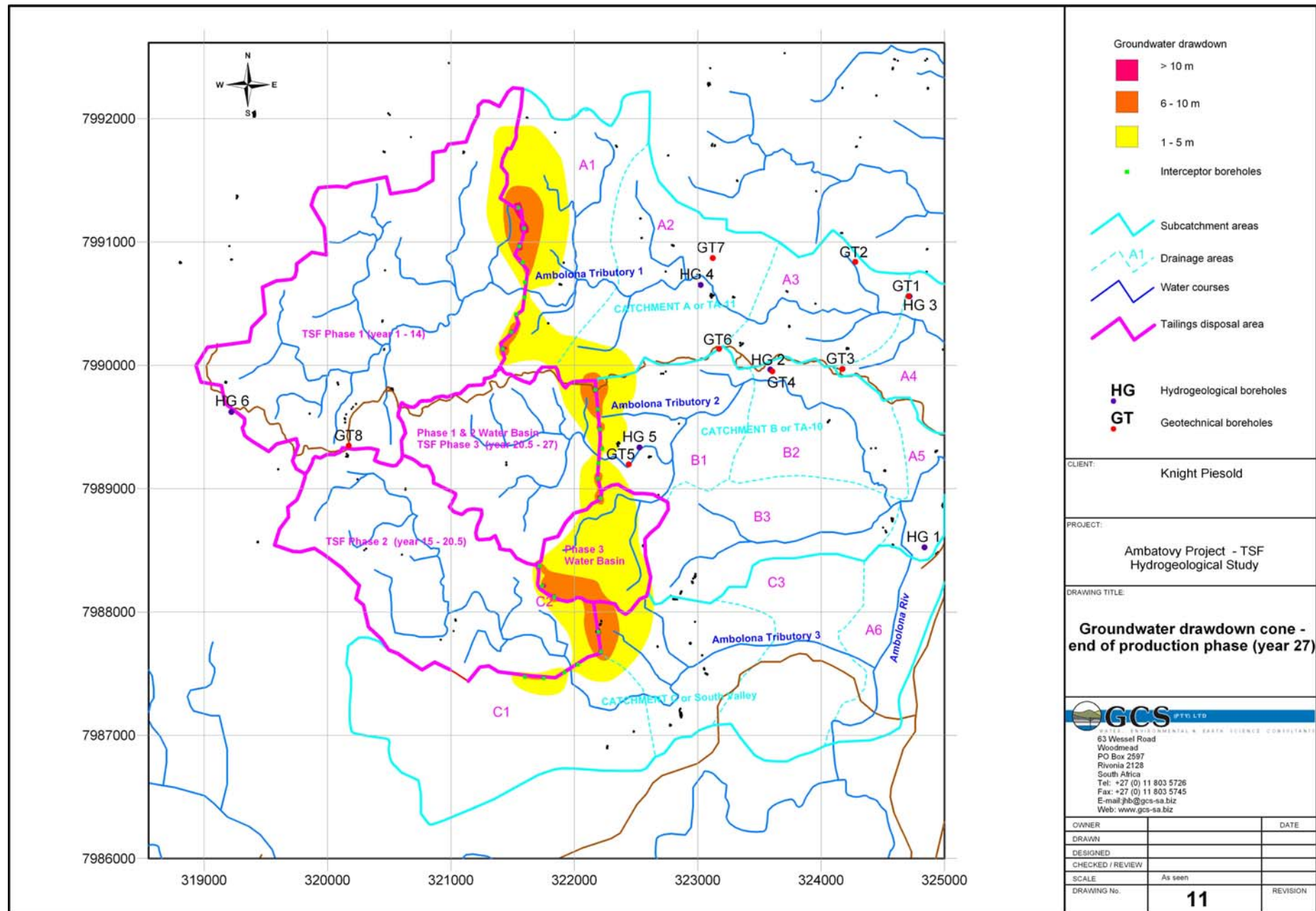
The impact of potential contaminated groundwater on stream water qualities will be small due to the interceptor borehole system. Calculated sulphate and manganese groundwater salt loads, seeping into the streams are listed in Appendix I. Stream water qualities are expected to comply with WHO drinking water guidelines.

3.3.1.4 Surface water flow reduction – groundwater component

Interceptor borehole abstraction will reduce the groundwater base flow component to stream flow. Groundwater component reduction for different drainage areas (Figure 3), expressed as the percentage groundwater flow reduction compared to baseline conditions, is listed in Table 14. Reduction in the groundwater component will mainly be restricted to drainage areas A1, B1 and C1. Groundwater contributes about 6 % of the total stream flow.

Table 14: Reduction in groundwater component to stream flows as a result of interceptor borehole abstraction - production phase.

Subcatchment drainage areas	Groundwater component reduction		
	Phase1 - year 14	Phase2 - year 20.5	Phase3 - year 27
Phase 1 TSF	-	-	-
Phase 2 TSF	9%	-	-
Phase 3 TSF	-	-	-
Phase 3 Water basin	5%	27%	-
A1	37%	41%	43%
A2	1%	1%	2%
B1	5%	5%	34%
B3	0%	1%	2%
C1	0%	43%	46%
C2	0%	10%	12



3.3.2 Decommissioning phase

The decommissioning phase is estimated to be in the order of 15 years. Seepage from the TSF is likely to improve within 10 to 16 years after tailings disposal stops (Section 3.2.2). This is based on the period that will be required to replace poor quality interstitial slurry water within the tailings void areas with clean rainwater. Interceptor borehole abstraction would therefore be continued over the 15-year decommissioning period. The abstraction rate would further be increased to maximise contaminant groundwater abstraction.

Identified impacts will be similar to that of the production phase and are discussed below.

3.3.2.1 Groundwater quality

Impacts on groundwater quality will be site specific as a result of the ongoing interceptor borehole abstraction. Potential impact on surrounding aquifers will be insignificant.

3.3.2.2 Groundwater levels

Ongoing abstraction from the interceptor boreholes will lower the surrounding groundwater levels. The abstraction rate will be more than that of the production phase, namely 1500 to 2000 m³/day, resulting in a larger groundwater drawdown cone. Figure 12 shows the extent of groundwater drawdown at the end of the decommissioning phase. The impact is local and limited to the drainage areas bordering the proposed TSF.

3.3.2.3 Surface water quality – groundwater seepage

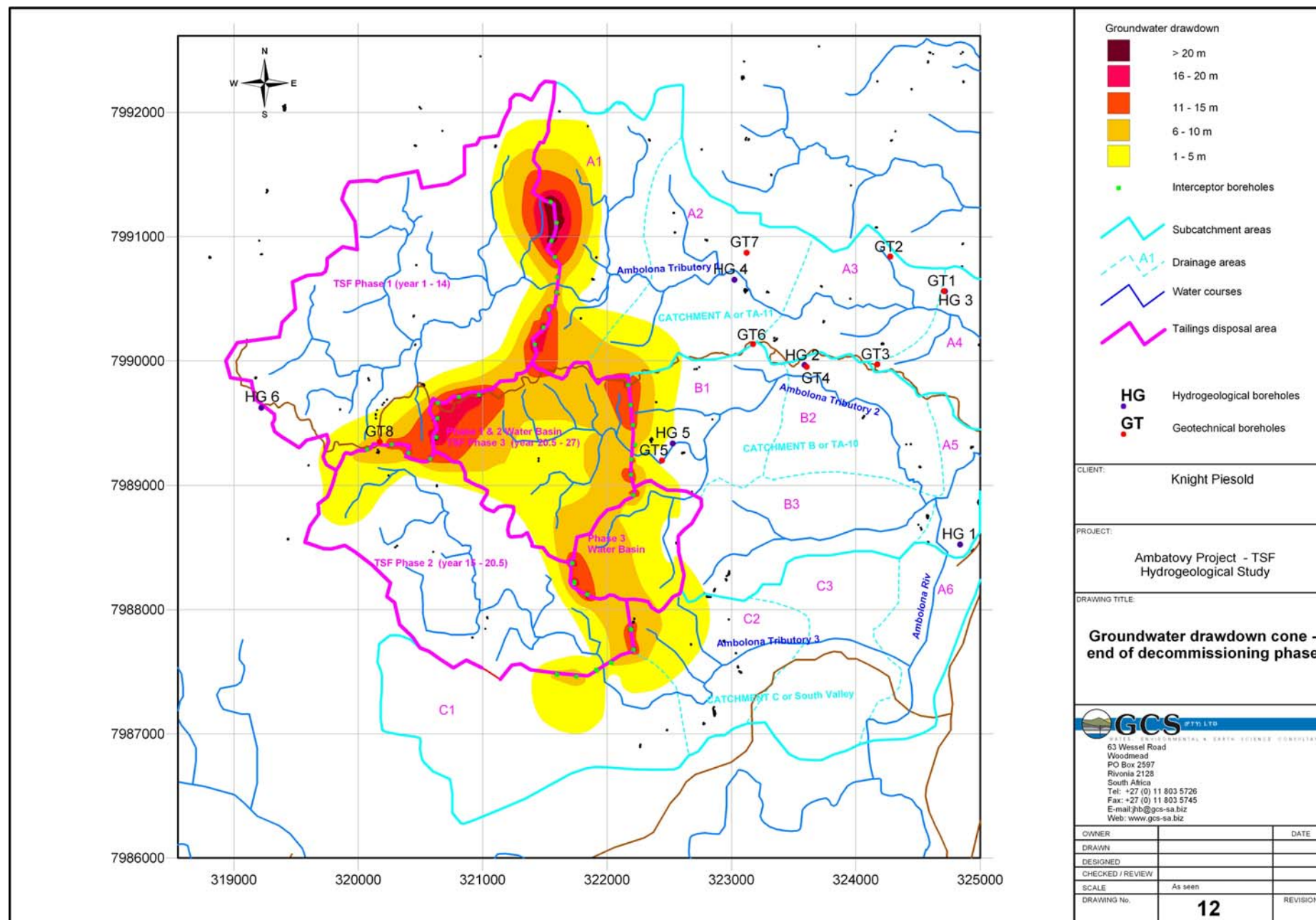
Impacts will be small, similar to the production phase. Stream water quality will comply with WHO drinking water guidelines.

3.3.2.4 Surface water flow reduction – groundwater component

The reduction in groundwater baseflow components for different drainage areas is summarised in Table 15. Groundwater contributes on average 6% to stream flow, which is small compared to surface runoff.

Table 15: Reduction in groundwater component to stream flows as a result of interceptor borehole abstraction – decommissioning phase.

Subcatchment drainage areas	Groundwater component reduction
	End of decommissioning phase
A1	69%
A2	8%
B1	75%
B3	1%
C1	46%
C2	15%



3.3.3 Long-term

3.3.3.1 Groundwater quality

Seepage quality from the TSF is likely to improve during this period and the interceptor borehole abstraction will therefore be stopped. The remnant salt plume, situated below the TSF, will be diluted compared to the production and decommissioning phase plumes due to the better quality tailings seepage and the effect of interceptor borehole abstraction.

Seepage rates would also be less than that of the production phase (20 to 60 % of production phase seepage rate) and would mainly be controlled by the rainfall infiltration rate.

The plume will migrate in an easterly direction (down-gradient of the TSF), once the interceptor borehole induced groundwater drawdown cone recovers. The prolonged decrease in groundwater recharge over the TSF area due to the low permeability of the tailings material will result in a decrease in groundwater transport velocities compared to baseline conditions. The contaminant plume will thus migrate at a relatively slow rate.

Further attenuation of the plume will mainly take place by dilution through rainwater recharge and aquifer mixing. Attenuation by sorption and chemical reaction would play a much less important role.

Figures 1a – c (H5), Appendix H, show the long-term (100 year) salt plumes for TDS, sulphate and manganese respectively. The affected zone is in the order of 500 to 1000 metres away from the TSF area for different constituents. TDS and SO₄ groundwater concentrations mainly comply with WHO drinking water guidelines. However, the Mn concentration exceeds the WHO guidelines, with a maximum 100-year groundwater concentration of 20 mg/l within the direct down-gradient TSF area. No hand dug wells or boreholes are situated within the affected zone. Salt balance calculations indicate that rainfall – surface runoff dilution would be sufficient in order to ensure that the stream Mn concentration complies with the WHO guideline value of 0.4 mg/l.

3.3.3.2 Groundwater levels

Groundwater levels will start to recover when interceptor borehole abstraction stops. However, seepage from the tailings dam will decrease in the long-term compared to the production phase. The average seepage flux rate will be 0.000065 m³/day/m², which is less than normal rainfall recharge. The decrease in recharge will decrease groundwater levels and gradients and therefore groundwater velocities. This will retard groundwater salt plume migration and will have a positive impact on groundwater quality.

The groundwater zone of impact as a result of decreasing recharge rates, reflected as a lowering of groundwater levels, will be limited to the tailings dam footprint area.

3.3.3.3 Surface water quality – groundwater seepage

Stream water quality will deteriorate slightly once interceptor borehole abstraction stops. This is due to the eastward migration of the TSF remnant salt plume (Section 3.3.3.1), which results in poor quality groundwater seepage affecting stream water quality. Calculated sulphate and manganese salt loads, seeping into streams are summarised in Appendix I. Rainwater – runoff dilution will be sufficient to dilute stream water quality to below WHO drinking water guideline values.

3.3.3.4 Surface water flow reduction – groundwater component

The reduction of groundwater recharge due to the blanketing effect of the tailings storage facility will reduce the volume of groundwater available for stream baseflow. The total reduction in groundwater availability for the neighbouring drainage areas is approximately $\pm 25\%$. However, the groundwater component of stream baseflow is small compared to surface runoff and the impact is therefore seen as small. Stream flow monitoring will be required to quantify the impact.

3.4 GROUNDWATER MANAGEMENT

Groundwater management and mitigation measures for different TSF phases are discussed below.

3.4.1 Production phase

Water basin liner

The installation of a liner system to elevation 28mamsl will prevent seepage losses from the water basin under normal operational conditions. Without a liner, the seepage volumes will increase by 3 times during maximum full supply conditions (typical during storm events). During normal operations the water basins should not be operated above 28mamsl.

The water basin for Phase 1 and 2 will be converted to a tailings basin for Phase 3. The water basin liner up to elevation 28mamsl will reduce seepage losses by approximately 35% towards the end of life of the tailings basin.

Interceptor borehole system

The interceptor borehole system will effectively minimise the migration of the salt plume from the TSF. The number of boreholes and system arrangement were optimised using the existing groundwater model. The proposed interceptor borehole arrangements for the various tailings depositional phases are shown in Figures 13a - d. Interceptor borehole spacing is ± 100 metres. Provision was also made for monitoring boreholes, situated midway between active interceptor boreholes. The main aims of these monitoring boreholes are:

- To monitor the extent of the groundwater drawdown zone. The data will be used to verify the effectiveness of the system.
- To act as back-up interceptor boreholes that could be used for pumping if monitoring indicates inadequate drawdown due to the potential preferential fracture flow characteristics of the aquifer.

Borehole numbers and abstraction rates are summarised in Table 16. The borehole arrangements of different tailing phases are discussed below:

Phase 1: The tailings pond (supernatant pond) will be relatively large during the initial stages of Phase 1 (Figure 13a). The pond will be situated close to the catchment divide between TA11 and the South Valley. Interceptor boreholes will mainly be concentrated along:

- The southwestern perimeter in order to prevent contamination of surface water bodies in the South Valley.
- The eastern TA11 embankment, protecting the Ambolona Tributary 1 or Catchment A.

The tailings pond moves to the east, close to TA10 catchment (also referred to as Catchment B), during the latter stages of Phase 1 (Figure 13b). The pond also becomes slightly smaller.

Emphases of interceptor borehole abstraction shifts more to the eastern TA11 embankment, compared to the southwestern perimeter.

Phase 2: Interceptor boreholes will be placed along the southeastern/eastern perimeter of the South Valley in order to mitigate the potential impact on the Ambolona Tributary 3 or Catchment C. Boreholes will also be placed along the northeastern perimeter, adjacent to the tailings pond area to minimise any potential impact on TA10 (Ambolona Tributary 2 or drainage area B2).

Phase 3: Interceptor borehole abstraction will be required when tailings deposition takes place above the liner system (Phase 1 – 2 Water basin liner). Boreholes will be placed mainly along the eastern embankment perimeter.

Table 16: Number of interceptor boreholes.

Tailings phase	Time interval (year)	Active intercepting boreholes	Monitoring boreholes	Total	Abstraction volumes (m ³ /day)
Phase 1	1 - 14	16	10	26	640
Phase 2	14 - 20.5	20	23	43	800
Phase 3	20.5 - 27	26	28	54	1040
Post - decommission	27 to 42	32	22	54	1500 - 2000

Groundwater monitoring

Proposed monitoring borehole positions are shown in Figure 14. These boreholes must be drilled and sampled before tailings disposal commences. Proposed boreholes are:

- HG 7 – down-gradient of Phase 1
- HG 8 – down-gradient of Phase 3 water basin
- HG 9 – embankment of Phase 3 water basin
- HG 10 – down-gradient of Phase 2
- HG 11 – on south-western divide of Phase 3 (South Valley)

Groundwater levels will be monitored on a regular basis (monthly) in order to determine seasonal fluctuations and also to quantify aquifer recharge.

Water quality will be monitored on a quarterly basis. This may be reduced to monthly intervals if and when required. Water samples must be analysed for similar chemical constituents tabled in Section 3.1.6. A yearly monitoring audit report will be compiled and will be submitted to the relevant authorities.

The groundwater model must be updated on a regular basis, once monitoring data becomes available (including tailings and surface water qualities and flows) for validation, recalibration and prediction.

Tailings storage facility operations

The tailings dam should be operated in such a manner that the tailings pond sizes are kept to a minimum. This will minimise infiltration and potential groundwater contamination. The cyclical placement of tailings in layers and the uniform raising of the tailings level will ensure that the layers are air-dried, reducing the pore pressures within the tailings and thus reducing the head of water over the foundation. The tailings facility water balance should be updated continuously as part of the water management plan.

3.4.2 Decommissioning phase and long-term

Interceptor borehole system

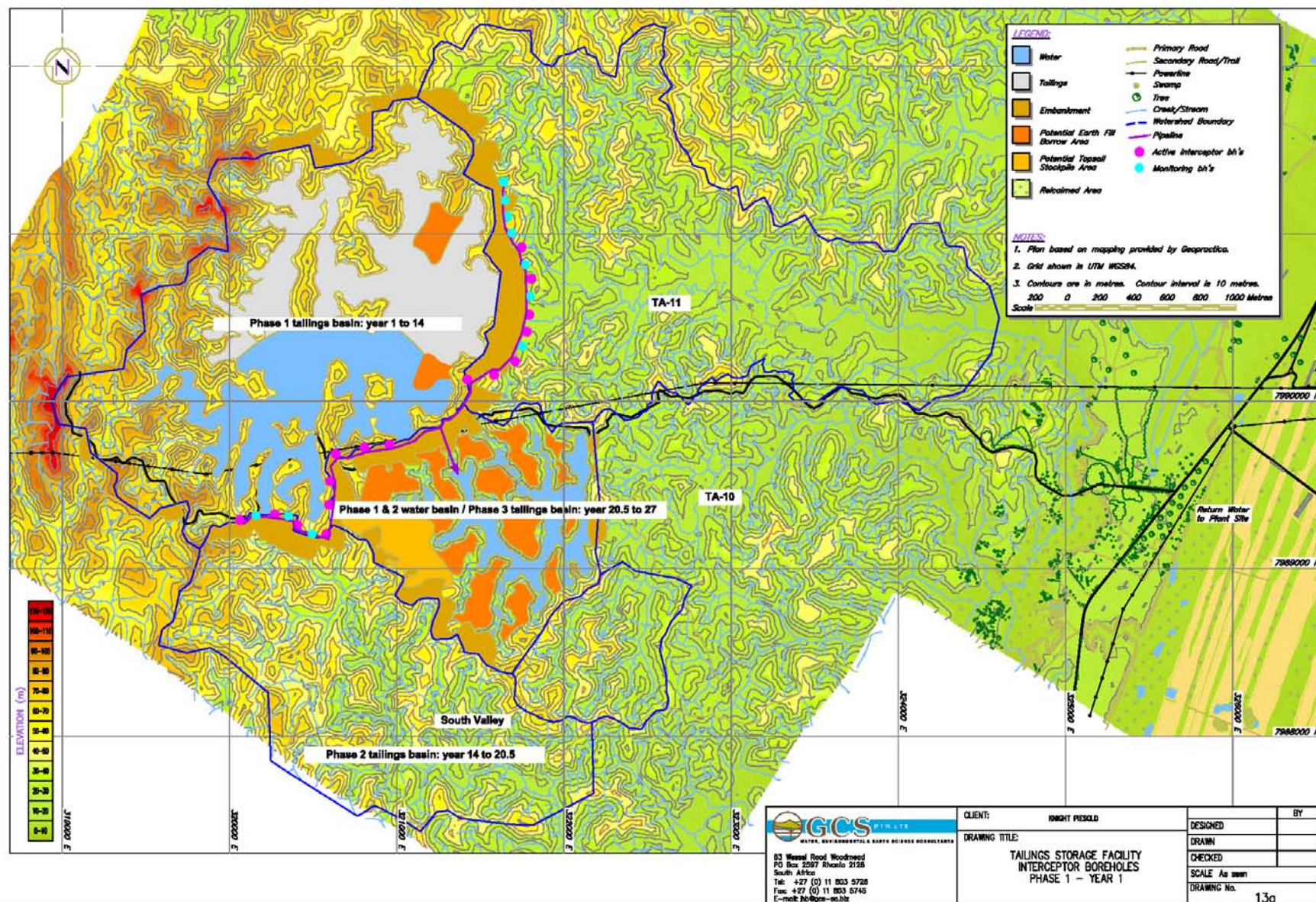
Figure 13e shows the interceptor borehole arrangement for the decommissioning phase. Decommissioning phase interceptor borehole abstraction is required to capture the ongoing contaminant seepage from the TSF, as well as the remnant salt plume that developed during the operational phase. Seepage from the TSF is likely to improve within 10 to 16 years after tailings deposition stops (average \pm 15 years). This is based on the period that will be required to replace poor quality water within the tailings void areas (slurry water) with clean water. Interceptor borehole abstraction will therefore be continued over the 15-year period. Abstraction would further be increased to maximise contaminant groundwater abstraction. Abstraction could be stopped at the end of the period.

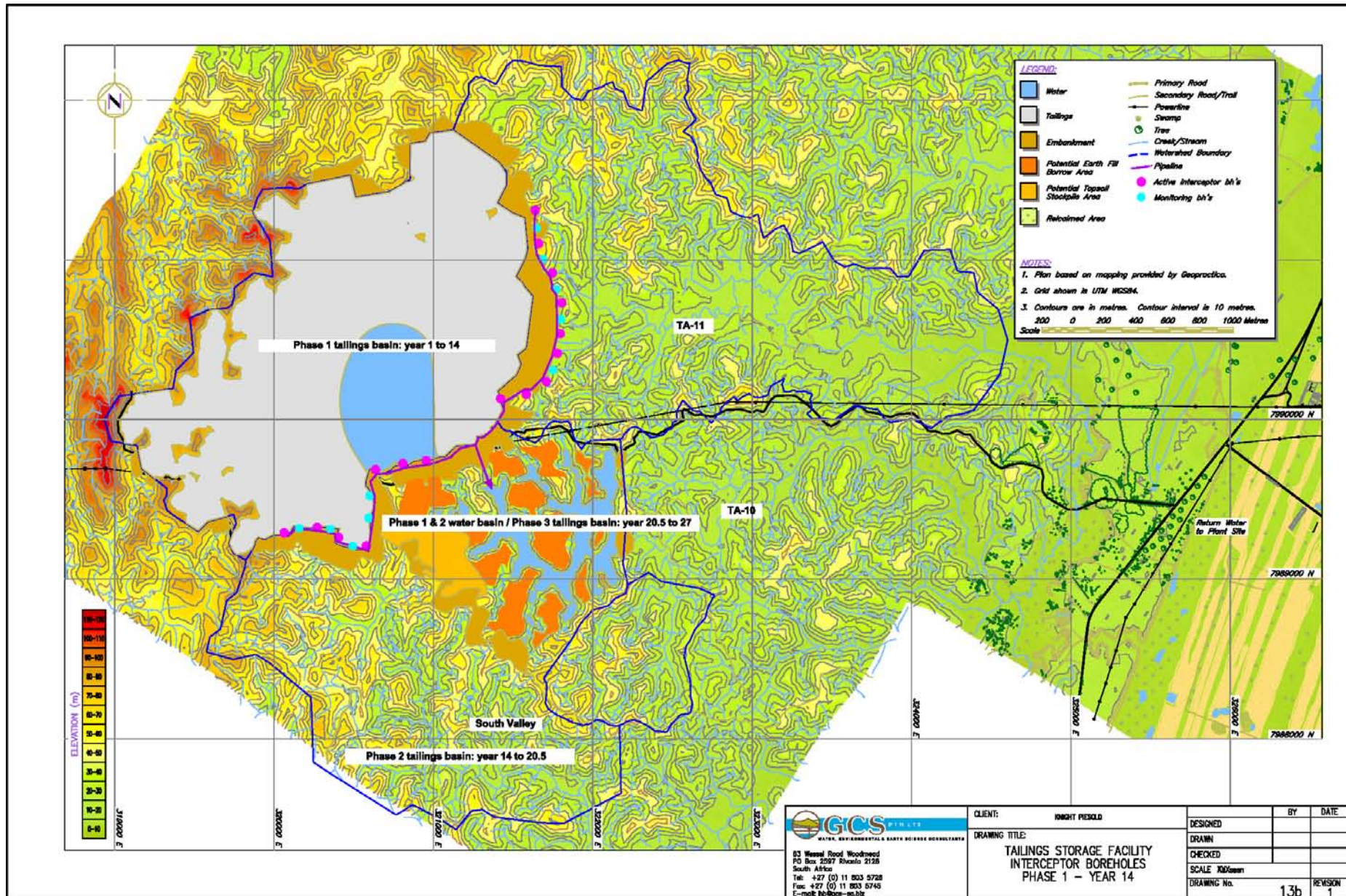
Groundwater monitoring

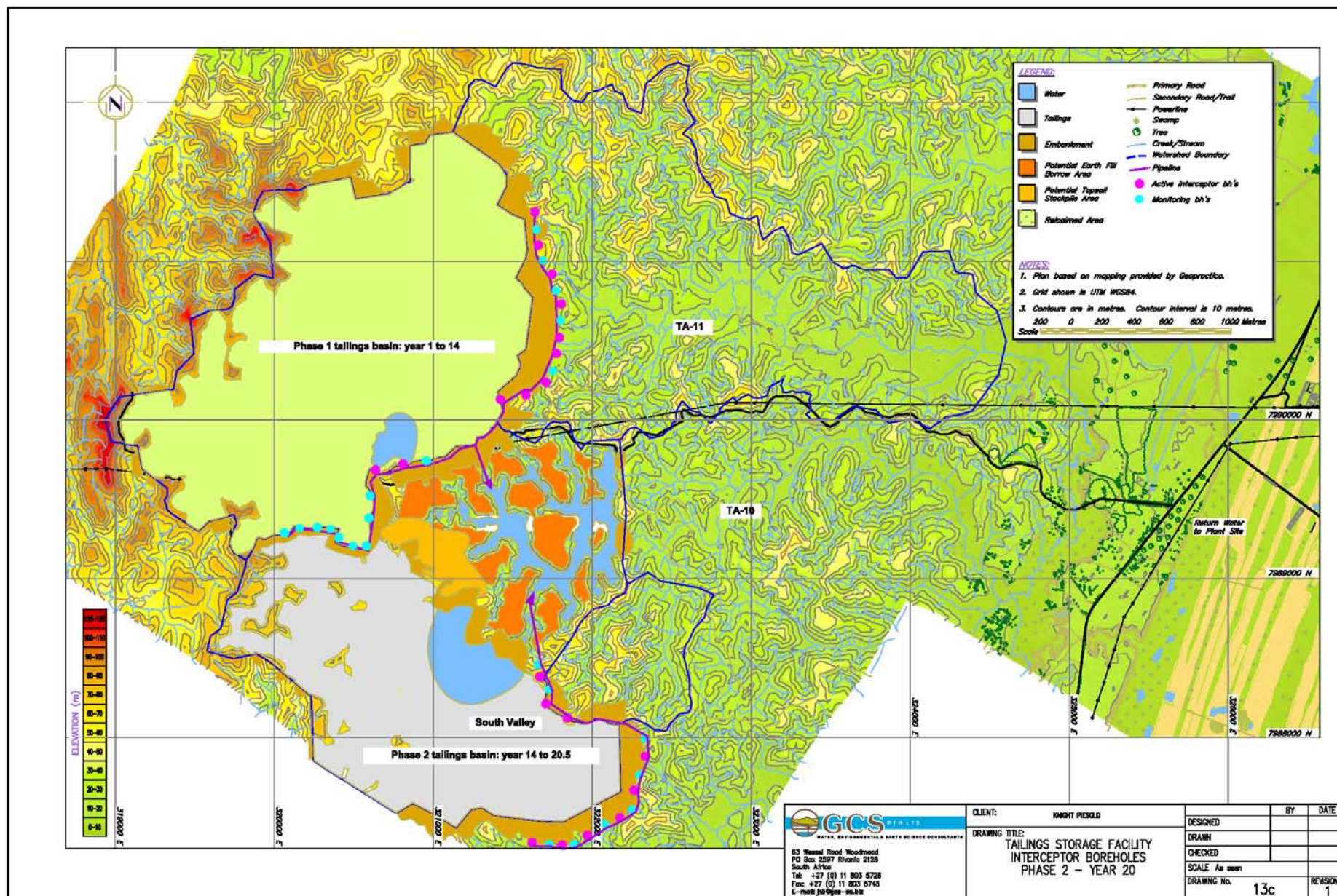
Groundwater monitoring points will be similar to that of the production phase. Monitoring of groundwater quality and levels will take place on a quarterly basis.

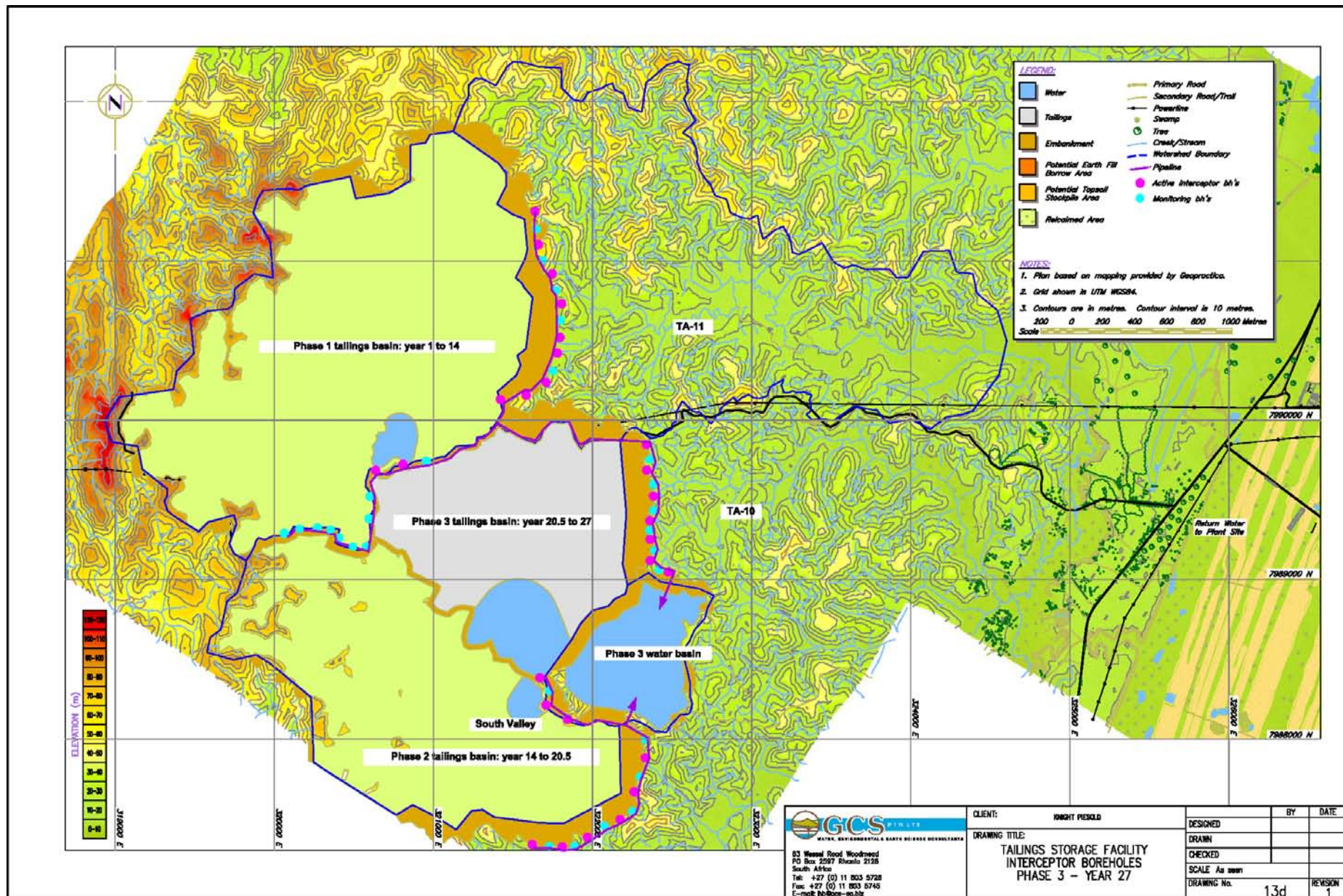
Tailings storage facility operations

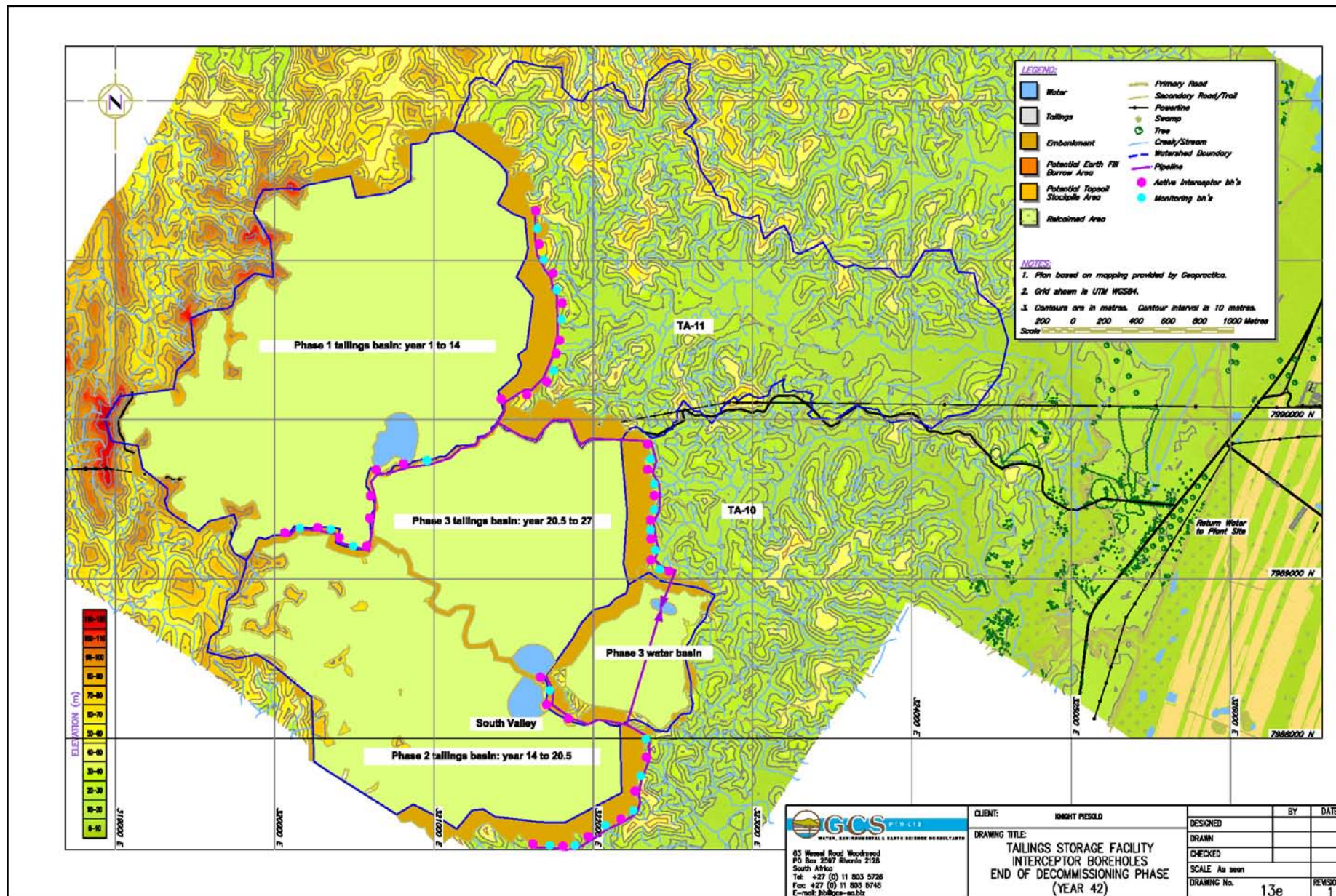
The closure design should allow for maximum run-off and minimum infiltration. Retention (ponding) of rainfall and runoff on top of the tailings will potentially result in a deterioration of water quality, as well as an increase of infiltration to aquifers.

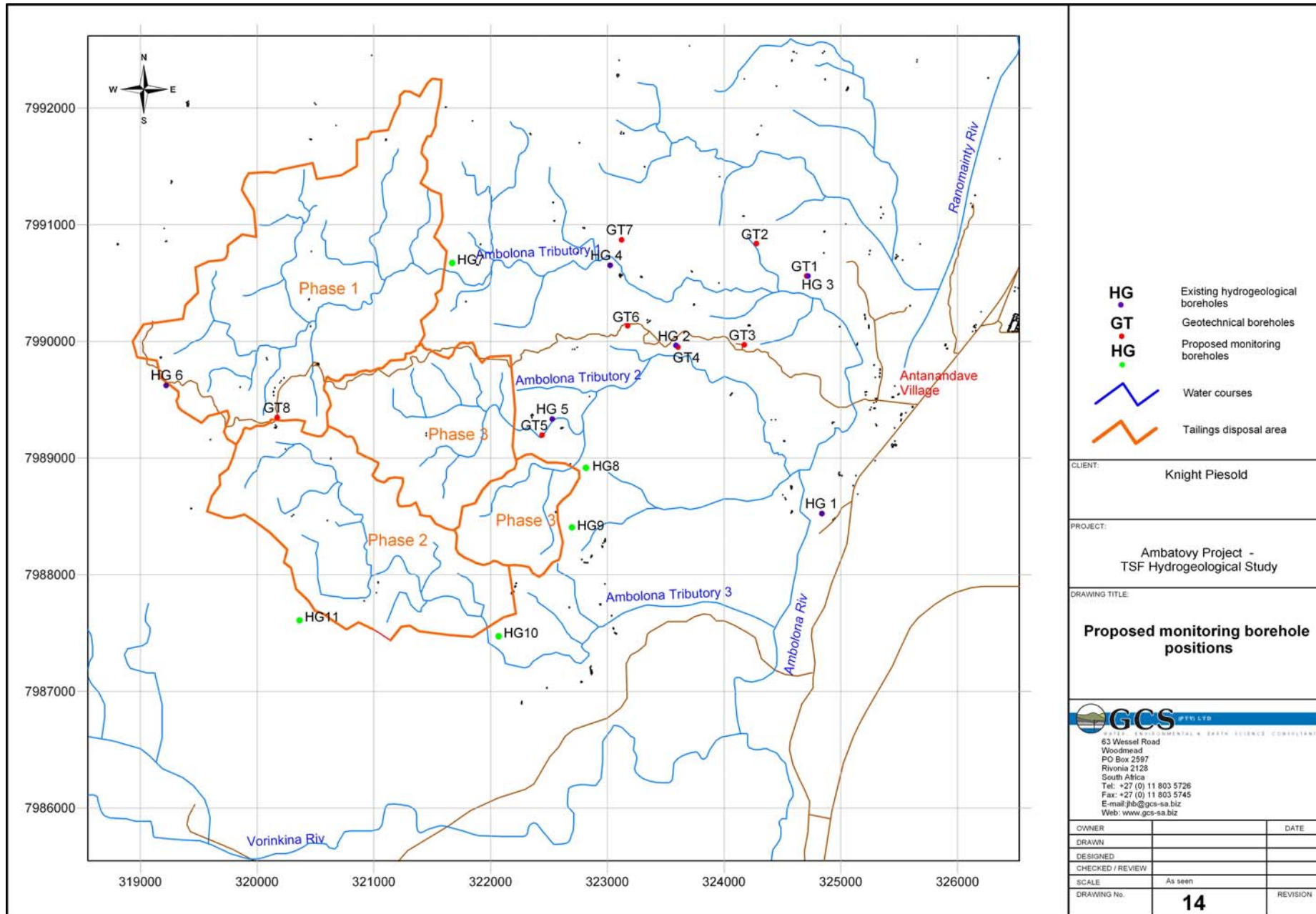












4 CONCLUSIONS

4.1 BASELINE HYDROGEOLOGY

- Groundwater gradients in general mimic the topographic surface and flow patterns are overall towards the east. Average groundwater gradients range between 1% and 2.5%.
- Groundwater discharge boundaries of concern are the Ambolona Tributary 1 (TA-10), Ambolona Tributary 2 (TA-11) and Ambolona Tributary 3 (South Valley).
- Three hydrogeological units were identified, namely:
 - An upper weathered inter-granular rock unit, consisting of decomposed gneiss and/or dolerite (average thickness 13 m).
 - An intermediate zone, consisting of weathering and fracturing (average thickness 8 m).
 - A lower, fresh rock, fractured unit.
- Transmissivities of aquifers, determined from aquifer testing, vary between 0.5 and 10 m²/day. Packer testing showed that the intermediate zone and fracture zone contribute most to groundwater flow.
- The groundwater quality for the area is suitable for potable use (WHO standards). Water is mainly magnesium, calcium, sodium - bicarbonate dominant.

4.2 SEEPAGE ANALYSIS

4.2.1 Tailings Basin

- The results indicate that relatively small volumes of water will be lost from the supernatant pond due to seepage, ranging from approximately 0.5% to 1.5% of the operational water that will be deposited with the tailings. The low seepage volumes are associated with the low permeability of the tailings. The volumes calculated might further be reduced by the accumulation of ultra fine material in this part of the tailings basin that will blanket this area.
- The construction of outer walls from material with a higher permeability than the tailings and the inclusion of drains should effectively prevent seepage to the outer slopes of the embankments.
- Seepage through the footprint of the tailings basins will be between 160m³/day and 416m³/day at maximum capacity.
- It is expected that seepage losses will be higher during the initial deposition period when the supernatant pond is in direct contact with the foundation, and when the tailings is unconsolidated, particularly during the first year of operation for Phase 1 and 2 when the rate of rise will be high.
- A supernatant pond depth of 1.5m was used for the modelling. Should the beach slopes be such that the depth of the pond increases significantly this will lead to a potential significant increase in seepage.
- The closure seepage analysis showed that the phreatic surface in the tailings basins will not be lowered significantly after closure of the facility. This could be due to the tailings characteristics and the influence of rainfall recharge to the facility.

4.2.2 Water Basin

- Seepage losses from the water basin without a liner system installed in the basin will be high due to the relatively high permeability of the foundation. Seepage volumes of 1200m³/day (approximately 4% of the operational water) are expected under normal operating conditions.
- The installation of a liner system to elevation 28mamsl will prevent seepage losses from the water basin under normal operational conditions. Under large storm event conditions the water could rise above the liner system for short periods to the full supply level of 36mamsl and seepage losses of 3400m³/day would be expected (approximately 9% of the operational water).

4.3 SOURCE WATER QUALITY (TAILINGS DAM AND WATER BASIN)

- Slurry water quality is sulphate (2500 mg/l), magnesium (2050 mg/l), calcium (450 mg/l) and manganese (230 mg/l) dominant. Other constituents have relatively low concentrations (Section 3.2.2).
- The net neutralising potential (NNP) of tailings material is 8.3 kg CaCO₃ / tonne. Leachate emanating from the tailings material is therefore not expected to be acidic due to the relatively high buffering capacity of minerals.
- Leachate quality is likely to become better with time as salts are flushed out of the rehabilitated tailings areas. Calculations based on the rate at which rainwater will replace tailings interstitial water indicate that better quality seepage could be expected 10 to 16 years (average 15 years) after tailings disposal stops.

4.4 IMPACTS & MANAGEMENT

Groundwater flow and contaminant transport modelling were conducted, using field hydrogeological parameters, tailings seepage rates and qualities. The aim of the groundwater model is to quantify the impact of the tailings dam on groundwater gradients and quality.

A summary of potential groundwater impacts and mitigation and/or management strategies are provided in Table 17. The assessment criteria are provided in Appendix J. The most important aspects are highlighted below:

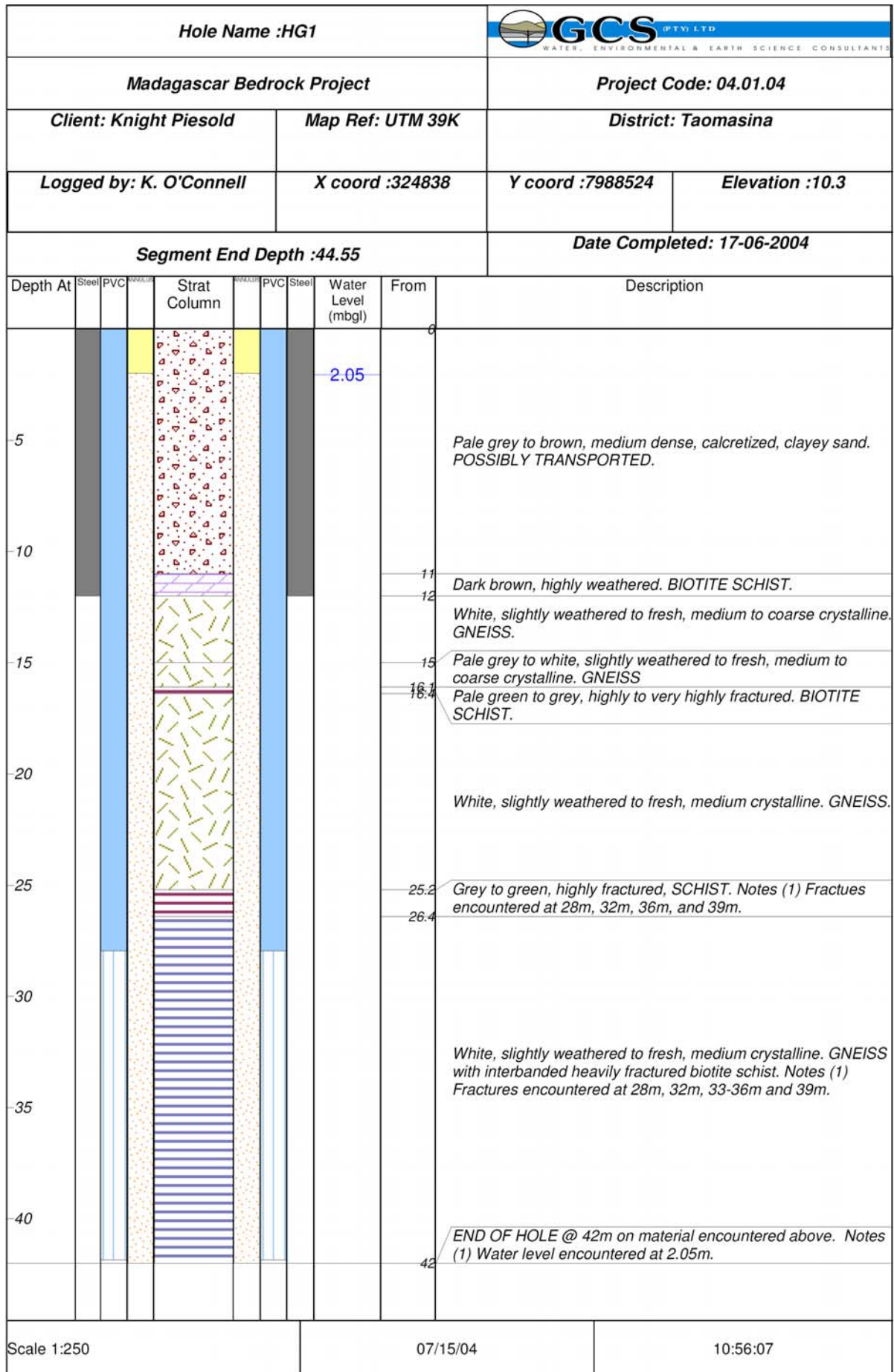
- Different mitigation options were investigated, namely drains, liner systems and interceptor boreholes. Scenario modelling indicates that a combination of water basin liners and interceptor boreholes during the production and decommissioning phases would prevent the lateral migration of the groundwater salt plume. The groundwater salt plume, resulting from tailings seepage, will be limited to the TSF footprint area during the production and decommissioning phases.
- The interceptor borehole system will minimise the potential impact of contaminant groundwater seepage on stream water quality.
- The blanketing effect of the low permeability tailings and interceptor borehole abstraction will lower groundwater levels and will reduce the groundwater component to stream flow. This impact will, however, be limited to the drainage areas immediately down-gradient of the TSF, namely A1, B1 and C1.


- Tailings seepage quality is likely to become better within time. It has been calculated that interceptor borehole abstraction will be required for about another 15 years after tailings disposal stops. The remnant groundwater plume will migrate down-gradient (up to 1000 m over a 100 year period), once interceptor borehole abstraction stops. The lateral migration of the groundwater salt plume over the long-term will be limited due to:
 - A decrease in the seepage rate from overlying tailings.
 - A decrease in groundwater gradients and flow velocities.
 - Rainfall recharge dilution and aquifer mixing.
 - A potential improvement of the leachate quality, emanating from the tailings material.
- Groundwater qualities in the long-term will mainly comply with WHO drinking water guidelines, except for manganese. Dilution from rainfall-runoff will, however, ensure that stream water quality (of all chemical constituents) will comply with WHO guidelines.


Table 15: Groundwater impact summary

Description	Probability	Duration	Intensity	Extent	Significance	Management
Groundwater contamination by seepage from the tailings dam – production & decommissioning phase.	Highly Probable	Long-term	Medium	Site	Medium	Water basin liner and drains Interceptor borehole system Water monitoring. Operating the Tailings Storage Facility in such a manner that the pond size is always kept to a minimum. Regular updates of impact predictions and mitigation measures. Compensation to water users affected
Groundwater contamination by seepage from the tailings dam – long-term.	Probable	Long-term	Medium	Local	Low	Tailings rehabilitation which will maximise run-off and minimise infiltration
Lowering of groundwater levels as a result of interceptor borehole abstraction - production & decommissioning phase.	Definite	Medium-term	Medium	Site/Local	Low	Optimisation of interceptor borehole abstraction in order to minimise groundwater drawdown. Groundwater level monitoring
Deterioration in stream flow qualities as a result of groundwater seepage – production & decommissioning phase.	Highly Probable	Medium-term	Low	Site	Medium	Water basin liner and drains Interceptor borehole system Water monitoring. Operating the Tailings Storage Facility in such a manner that the pond size is always kept to a minimum. Regular updates of impact predictions and mitigation measures. Compensation to water users affected
Deterioration in stream flow qualities as a result of groundwater seepage – long-term.	Probable	Long-term	Low/medium	Local	Low	Tailings rehabilitation which will maximise run-off and minimise infiltration
Decrease in groundwater baseflow as a result of interceptor borehole abstraction and low permeability tailings – production phase, decommissioning phase and long-term.	Probable	Permanent	Low	Local	Low	Optimisation of interceptor borehole abstraction in order to minimise groundwater drawdown. Groundwater level monitoring Stream flow monitoring.


APPENDIX A: BOREHOLE LOGS





Hole Name :HG2								 GCS (PTY) LTD WATER, ENVIRONMENTAL & EARTH SCIENCE CONSULTANTS			
Madagascar Bedrock Project								Project Code: 04.01.04			
Client: Knight Piesold				Map Ref: UTM 39K				District: Taomasina			
Logged by: K. O'Connell				X coord :323588				Y coord :7989966		Elevation :21	
Segment End Depth :44.55								Date Completed: 17-06-2004			
Depth At	Steel	PVC	Strat Column	PVC	Steel	Water Level (mbgl)	From	Description			
							0	Pale tan, highly to completely weathered. DOLERITE.			
							2.5	Abundant weathered corestones (cobble size), in a pale brown, clayey silt RESIDUAL DOLERITE matrix.			
							3.5				
5						5.55					
10											
15								Dark grey, moderate to slightly weathered. DOLERITE.			
20											
25											
30							30	END OF HOLE @ 30m on material encountered above. Notes (1) Water level encountered at 5.55m.			
35											
40											
Scale 1:250						07/15/04			10:56:07		

Hole Name :HG3										 GCS (PTY) LTD WATER · ENVIRONMENTAL & EARTH SCIENCE CONSULTANTS									
Madagascar Bedrock Project										Project Code: 04.01.04									
Client: Knight Piesold					Map Ref: UTM 39K					District: Taomasina									
Logged by: K. O'Connell					X coord :324716					Y coord :7990560					Elevation :12.6				
Segment End Depth :44.55										Date Completed: 17-06-2004									
Depth At	Steel	PVC	PVC	Strat Column	PVC	Steel	Water Level (mbgl)	From	Description										
								0											
-5							2.76												
-10																			
-15																			
-20								20	Reddish brown, highly weathered. BIOTITE SCHIST.										
								22	Brown, slightly weathered, coarse crystalline. PEGMATITE VEIN.										
-25								24	White to yellowish green, slightly to moderately weathered. GNEISS.										
								26	Pale brown, moderately weathered, coarse crystalline. GNEISS.										
-30								30	Creamy brown, slightly weathered, highly fractured. BIOTITE SCHIST.										
								31	Pale grey, slightly weathered to fresh. GNEISS.										
-35								34	Grey and white, moderately weathered to fresh, banded. GNEISS. Notes (1) Fracturing encountered from 34-35.2m.										
								39.3	END OF HOLE @ 39.3m on material encountered above. Notes (1) Water level encountered at 2.76m.										
-40																			

Scale 1:250	07/15/04	10:56:07
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Hole Name :HG4								 GCS (PTY) LTD WATER · ENVIRONMENTAL & EARTH SCIENCE CONSULTANTS			
Madagascar Bedrock Project								Project Code: 04.01.04			
Client: Knight Piesold				Map Ref: UTM 39K				District: Taomasina			
Logged by: K. O'Connell				X coord :323024				Y coord :7990652		Elevation :31	
Segment End Depth :44.55								Date Completed: 17-06-2004			
Depth At	Steel	PVC	Strat Column	PVC	Steel	Water Level (mbgl)	From	Description			
							0	Yellow, silty clay with a coarse gravel component. TRANSPORTED.			
5							11	Pale tan, highly weathered, medium to coarse crystalline. GNEISS.			
10							13.5				
15							25	White with dark grey banding, moderate to slightly weathered, closely fractured, medium to coarse crystalline. GNEISS.			
20							25				
25							36	White with dark grey banding, slightly weathered, widely fractured, medium to coarse crystalline. GNEISS.			
30							36	END OF HOLE @ 36m on material encountered above. Notes (1) Water level encountered at 13.5m.			
35											
40											
Scale 1:250						07/15/04			10:56:07		

Hole Name :HG5										 GCS (PTY) LTD WATER · ENVIRONMENTAL & EARTH SCIENCE CONSULTANTS																			
Madagascar Bedrock Project										Project Code: 04.01.04																			
Client: Knight Piesold					Map Ref: UTM 39K					District: Taomasina																			
Logged by: K. O'Connell					X coord :322528					Y coord :7989334					Elevation :33														
Segment End Depth :44.55										Date Completed: 17-06-2004																			
Depth At	Steel	PVC	PVC	Strat Column	PVC	Steel	Water Level (mbgl)	From	Description																				
								0	Red to brown, soft to firm, silty clay. ALLUVIUM.																				
								2																					
5									Brown, highly weathered, medium crystalline. DOLERITE.																				
								8	Pale brown to orange, highly weathered, medium to coarse crystalline. DOLERITE.																				
								9																					
10									Very dark grey to black, highly weathered, schistosity exhibited in jointing, medium to coarse crystalline. GNEISS.																				
								12																					
15																													
20									Pale grey streaked white, slightly weathered to fresh, moderately fractured, medium to coarse crystalline. GNEISS. Notes (1) Fractures encountered at 13m and 17m.																				
25																													
30																													
35								35	END OF HOLE @ 35m on material encountered above. Notes (1) No water level recorded due to sedimentation of the borehole.																				
40																													
Scale 1:250										07/15/04										10:56:07									

Hole Name :HG6										 GCS (PTY) LTD WATER · ENVIRONMENTAL & EARTH SCIENCE CONSULTANTS																			
Madagascar Bedrock Project										Project Code: 04.01.04																			
Client: Knight Piesold					Map Ref: UTM 39K					District: Taomasina																			
Logged by: K. O'Connell					X coord :319221					Y coord :7989622					Elevation :67														
Segment End Depth :44.55										Date Completed: 17-06-2004																			
Depth At	Steel	PVC	NIRALUS	Strat Column	NIRALUS	PVC	Steel	Water Level (mbgl)	From	Description																			
									0	Pale brown, moderate to highly weathered, medium to coarse crystalline. DOLERITE.																			
									2.5	Cream, moderately weathered, medium crystalline. GNEISS.																			
5									4																				
										Dark grey, moderate to highly weathered. BIOTITE SCHIST with some weathered gneiss banding.																			
10																													
								13.77																					
15																													
									18.5	White, fresh. PEGMATITE VEIN.																			
20									20																				
										Dark grey, moderate to slightly weathered. BIOTITE SCHIST. Notes (1) Fractures encountered at 24m and 28m.																			
25																													
									31																				
30										Black to dark grey, fresh,highly mineralised. PEGMATITE VEIN.																			
									36																				
35										Black, moderate to fresh, widely fractured. SCHISTOTIC MIGMATITE. Notes (1) Fractures encountered at 36m and 39m.																			
									39																				
40										Grey, fresh, medium to coarse crystalline, widely fractured. BANDED GNEISS. Notes (1) Fracture encountered at 40m.																			
									41.7	END OF HOLE @ 41.7m on material encountered above. Notes (1) Water level encountered at 13.77m.																			
Scale 1:250										07/15/04										10:56:07									


APPENDIX B: GROUNDWATER COMPONENT TO STREAM FLOW

Basin	Distance from embankment toe (m)	Groundwater baseflow flux (m³/annum)					Comment
		Baseline	Year 14	Year 20	Year 27	Long - term (post closure)	
A	0	496400					Upstream from embankment
	250	40150	94900	98550	102200	32850	
	750	149650	175200	182500	182500	138700	
	1250	58400	62050	62050	62050	58400	
	1750	102200	102200	102200	102200	102200	
	2250	76650	76650	76650	76650	76650	
	2750	69350	69350	69350	69350	69350	
	3250	73000	73000	73000	73000	73000	
	3750	76650	76650	76650	76650	76650	
	4250	62050	62050	62050	62050	62050	
Total	4750	62050	62050	62050	62050	62050	QESF-203
		1266550	854100	865050	868700	751900	
B	0	277400					Upstream from embankment
	250	65700	80300	91250	131400	80300	
	750	80300	80300	80300	94900	76650	
	1250	51100	54750	54750	54750	51100	
	1750	58400	58400	58400	58400	58400	
	2250	65700	65700	65700	65700	65700	
	2750	58400	58400	58400	58400	58400	
	3250	65700	65700	65700	65700	65700	
	3750	62050	62050	62050	62050	62050	
	4250	40150	40150	40150	40150	40150	
Total	4750	94900	94900	94900	94900	94900	QESF-207 (Also includes part of A5)
B3	500	69350	69350	73000	76650	69350	
	1000	51100	51100	51100	51100	51100	
	1500	54750	54750	54750	54750	54750	
Total		1095000	835850	850450	908850	828550	
C	0	434350	485450				Upstream from embankment
	250	47450	47450	94900	98550	40150	
	750	73000	73000	83950	87600	69350	
	1250	73000	73000	76650	80300	73000	
	1750	73000	73000	73000	80665	73000	
	2250	62050	62050	62050	62050	62050	
	2750	54750	54750	54750	54750	54750	
	3250	109500	109500	109500	109500	109500	
	Total		927100	978200	554800	573415	


Basin	Distance from embankment toe (m)	Baseline	Cumulative groundwater baseflow flux (m ³ /annum)				Comment
			Year 14	Year 20	Year 27	Long - term (post closure)	
A	0	496400					Upstream from embankment
	250	536550	94900	98550	102200	32850	
	750	686200	270100	281050	284700	171550	
	1250	744600	332150	343100	346750	229950	
	1750	846800	434350	445300	448950	332150	
	2250	923450	511000	521950	525600	408800	
	2750	992800	580350	591300	594950	478150	
	3250	1065800	653350	664300	667950	551150	
	3750	1142450	730000	740950	744600	627800	
	4250	1204500	792050	803000	806650	689850	
	4750	1266550	854100	865050	868700	751900	QESF-203
B	0	277400					Upstream from embankment
	250	343100	80300	91250	131400	80300	
	750	423400	160600	171550	226300	156950	
	1250	474500	215350	226300	281050	208050	
	1750	532900	273750	284700	339450	266450	
	2250	598600	339450	350400	405150	332150	
	2750	657000	397850	408800	463550	390550	
	3250	722700	463550	474500	529250	456250	
	3750	784750	525600	536550	591300	518300	
	4250	824900	565750	576700	631450	558450	
	4750	1095000	835850	846800	901550	828550	QESF-207 (Also includes part of A5)
B3	0						
	500	69350	69350	69350	69350	69350	
	1000	120450	120450	120450	120450	120450	
	1500	175200	175200	175200	175200	175200	
C	0	434350	434715				Upstream from embankment
	250	481800	482165	94900	98550	40150	
	750	554800	555165	178850	186150	109500	
	1250	627800	628165	255500	266450	182500	
	1750	700800	701165	328500	347115	255500	
	2250	762850	763215	390550	409165	317550	
	2750	817600	817965	445300	463915	372300	
	3250	927100	927465	554800	573415	481800	Border of groundwater model = estimated additional baseflow up to QESF-201 = 120 m ³ /day (43800 m ³ /annum).
Total		3288650	2617415	2266650	2343665	2062250	C1 not include - estimated baseflow = 850 m ³ /day (310250 m ³ /day)

*² averaged daily values


APPENDIX C: PACKER TEST DATA


GCS (Pty) Ltd
WATER, ENVIRONMENTAL & EARTH SCIENCES CONSULTANTS

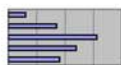
AMBATOVY PROJECT: TAILINGS DAM STUDY
BOREHOLE: GT1

DATE	STAGES	TEST DEPTH (m)	TESTING TIME	GAUGE PRESURES		WATER INTAKE	LUGEON VALUE		PERMEABILITY m/day	LUGEON PATTERN	PATTERN INTERPRETATION	GEOLOGY	COMMENTS
	METERS		REQUIRED MINUTES	REQUIRED PRESURES	ACTUAL PRESURES	LITRES	FOR EACH TEST	REPRESENTATIVE FOR EACH STAGE					
14-05-2004	from	2	10	165	165	0	0.00	0.16	0.000		INSUFFICIENT DATA	Sandy Silt from Residual Gneiss	Test zone consists of silt which possibly accounts for the low lugeon and permeability
	18.5	2	10	280	280	1	0.2		0.007				
	to	2	10	395	395	5	0.6		0.017				
	20.5	2	10	280	280	0	0.00		0.000				
		2	10	165	165	0	0.00		0.000				
Average									0.0047				


BOREHOLE: GT1


DATE	STAGES	TEST DEPTH (m)	TESTING TIME	GAUGE PRESURES		WATER INTAKE	LUGEON VALUE		PERMEABILITY m/day	LUGEON PATTERN	PATTERN INTERPRETATION	GEOLOGY	COMMENTS
	METERS		REQUIRED MINUTES	REQUIRED PRESURES	ACTUAL PRESURES	LITRES	FOR EACH TEST	REPRESENTATIVE FOR EACH STAGE					
14-05-2004	from	1.5	10	190	190	16	6	6	0.944		VOID FILLING	Sandy silt becoming sandy Gravel	Void filling has possibly occurred which accounts for low permeability value
	21	1.5	10	330	330	35	7		0.051				
	to	1.5	10	475	400	25	4		0.020				
	22.5	1.5	10	330	330	54	11		0.080				
		1.5	10	190	190	0	0		0.000				
Average									0.2189				

BOREHOLE: GT1

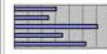
DATE	STAGES	TEST DEPTH (m)	TESTING TIME	GAUGE PRESURES		WATER INTAKE	LUGEON VALUE		PERMEABILITY m/day	LUGEON PATTERN	PATTERN INTERPRETATION	GEOLOGY	COMMENTS
	METERS		REQUIRED MINUTES	REQUIRED PRESURES	ACTUAL PRESURES	LITRES	FOR EACH TEST	REPRESENTATIVE FOR EACH STAGE					
14-05-2004	from	1.5	10	220	220	3	1	1	-		TURBULENT WITH DILATION	Very soft rock, micaceous Gneiss	Possible low fracture frequency which accounts for low lugeon value
	24.8	1.5	10	390	390	7	1		0.044				
	to	1.5	10	555	555	13	2		0.042				
	26.3	1.5	10	390	390	5	1		0.032				
		1.5	10	220	220	1	0		-				
Average									0.0392				

BOREHOLE: GT1


DATE	STAGES	TEST DEPTH (m)	TESTING TIME	GAUGE PRESURES		WATER INTAKE	LUGEON VALUE		PERMEABILITY m/day	LUGEON PATTERN	PATTERN INTERPRETATION	GEOLOGY	COMMENTS
	METERS		REQUIRED MINUTES	REQUIRED PRESURES	ACTUAL PRESURES	LITRES	FOR EACH TEST	REPRESENTATIVE FOR EACH STAGE					
14-05-2004	from	2	10	240	240	0	0	0.34	0.000		TURBULENT WITH DILATION	Very soft rock, micaceous Gneiss	Possible low fracture frequency which accounts for low lugeon value
	26.5	2	10	420	420	5	1		0.022				
	to	2	10	600	600	9	1		0.020				
	28.5	2	10	420	420	3	0		0.013				
		2	10	240	240	0	0		0.000				
Average									0.0184				




AMBATOVY PROJECT: TAILINGS DAM STUDY
BOREHOLE: GT4

DATE	STAGES METERS	TEST DEPTH (m)	TESTING TIME REQUIRED MINUTES	GAUGE PRESURES		WATER INTAKE LITRES	LUGEON VALUE REPRESENTATIVE FOR EACH STAGE		PERMEABILITY m/day	LUGEON PATTERN	PATTERN INTERPRETATION	GEOLOGY	COMMENTS
20-05-2004	from 12.5	2	10	115	115	12	4	5	9.625		TURBULENT	Clayey Silt with corestones from 12.4m to 12.64m	Test zone consists of corestones in matrix of clayey silt, clayey silt has been washed out, could account for high permeability
	to 14.5	2	10	200	200	14		4	0.131				
		2	10	280	280	34		6	0.164				
		2	10	200	200	10		3	0.093				
		2	10	115	115	7		3	5.615				
	AVERAGE								3.126				

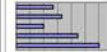
BOREHOLE: GT4


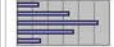

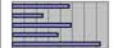
DATE	STAGES METERS	TEST DEPTH (m)	TESTING TIME REQUIRED MINUTES	GAUGE PRESURES		WATER INTAKE LITRES	LUGEON VALUE REPRESENTATIVE FOR EACH STAGE		PERMEABILITY m/day	LUGEON PATTERN	PATTERN INTERPRETATION	GEOLOGY	COMMENTS
20-05-2004	from 14.5	2	10	130	130	8	5	3	-		TURBULENT	Residual to Soft Rock Dolerite	Test zone is tight with minimal or low fracture frequency
	to 16.5	2	10	230	230	26		6	0.22				
		2	10	330	330	32		5	0.13				
		2	10	230	230	28		6	0.23				
		2	10	130	130	9		3	-				
	AVERAGE								0.19				


BOREHOLE: GT4

DATE	STAGES METERS	TEST DEPTH (m)	TESTING TIME REQUIRED MINUTES	GAUGE PRESURES		WATER INTAKE LITRES	LUGEON VALUE REPRESENTATIVE FOR EACH STAGE		PERMEABILITY m/day	LUGEON PATTERN	PATTERN INTERPRETATION	GEOLOGY	COMMENTS
20-05-2004	from 16.5	5	10	150	150	20	2	3	0.06		INSUFFICIENT DATA	Medium Hard Rock Dolerite	Test zone is tight with minimal or low fracture frequency
	to 21.5	5	10	260	260	20		2					
		5	10	375	375								
		5	10	260	260								
		5	10	150	150								
	MAXIMUM HEAD OF THE PUMP												
								AVERAGE	0.0600				

BOREHOLE: GT4


DATE	STAGES METERS	TEST DEPTH (m)	TESTING TIME REQUIRED MINUTES	GAUGE PRESURES		WATER INTAKE LITRES	LUGEON VALUE REPRESENTATIVE FOR EACH STAGE		PERMEABILITY m/day	LUGEON PATTERN	PATTERN INTERPRETATION	GEOLOGY	COMMENTS
20-05-2004	from 16.5	2	10	150	150	90	29	30	-		TURBULENT	Medium Hard Rock Dolerite	The rock mass is closely jointed (fracture) could account for higher permeability
	to 18.5	2	10	260	260	152		29	1.150				
		2	10	375	375	210		28	0.762				
		2	10	260	260	149		29	1.127				
		2	10	150	150	85		28	-				
	AVERAGE								1.013				

GCS														AMBATOVY PROJECT: TAILINGS DAM STUDY													
BOREHOLE: GT5														BOREHOLE: GT5													
DATE	STAGES	TEST DEPTH (m)	TESTING TIME REQUIRED MINUTES	GAUGE PRESURES		WATER INTAKE	LUGEON VALUE		PERMEABILITY m/day	LUGEON PATTERN	PATTERN INTERPRETATION	GEOLOGY	COMMENT														
	METERS			REQUIRED PRESURES	ACTUAL PRESURES	LITRES	FOR EACH TEST	REPRESENTATIVE FOR EACH STAGE																			
12-06-2004	from	2	10	65	65	29	22	36	1.108		DILATION	Very soft rock Dolerite	High lugeon value and permeability due to high weathering and possible washing out of the silt during drilling.														
	7	2	10	110	110	96	44		1.167																		
	to	2	10	160	160	166	52		1.148																		
	9	2	10	110	110	93	42		1.130																		
		2	10	65	65	26	20		0.993																		
AVERAGE									1.109																		
BOREHOLE: GT5														BOREHOLE: GT5													
DATE	STAGES	TEST DEPTH (m)	TESTING TIME REQUIRED MINUTES	GAUGE PRESURES		WATER INTAKE	LUGEON VALUE		PERMEABILITY	LUGEON PATTERN	PATTERN INTERPRETATION	GEOLOGY	COMMENT														
	METERS			REQUIRED PRESURES	ACTUAL PRESURES	LITRES	FOR EACH TEST	REPRESENTATIVE FOR EACH STAGE																			
12-06-2004	from	2	10	80	80	12	8	15	0.602		DILATION	Very soft rock Gneiss	Rock is highly weathered and closely jointed, possibility of infilling of joints														
	9	2	10	140	140	51	18		0.538																		
	to	2	10	200	200	105	26		0.619																		
	11	2	10	140	140	47	17		0.496																		
		2	10	80	80	11	7		0.551																		
AVERAGE									0.561																		
BOREHOLE: GT5														BOREHOLE: GT5													
DATE	STAGES	TEST DEPTH (m)	TESTING TIME REQUIRED MINUTES	GAUGE PRESURES		WATER INTAKE	LUGEON VALUE		PERMEABILITY	LUGEON PATTERN	PATTERN INTERPRETATION	GEOLOGY	COMMENT														
	METERS			REQUIRED PRESURES	ACTUAL PRESURES	LITRES	FOR EACH TEST	REPRESENTATIVE FOR EACH STAGE																			
12-06-2004	from	2	10	100	100	70	35	35	3.509		LAMINAR	Hard rock Gneiss	Possible large fracture within test zone accounts for high lugeon and permeability														
	11	2	10	170	170	123	36		1.147																		
	to	2	10	250	250	194	39		0.937																		
	13	2	10	170	170	119	35		1.110																		
		2	10	100	100	59	30		2.958																		
AVERAGE									1.932																		
BOREHOLE: GT5														BOREHOLE: GT5													
DATE	STAGES	TEST DEPTH (m)	TESTING TIME REQUIRED MINUTES	GAUGE PRESURES		WATER INTAKE	LUGEON VALUE		PERMEABILITY	LUGEON PATTERN	PATTERN INTERPRETATION	GEOLOGY	COMMENT														
	METERS			REQUIRED PRESURES	ACTUAL PRESURES	LITRES	FOR EACH TEST	REPRESENTATIVE FOR EACH STAGE																			
12-06-2004	from	2	10	135	135	90	33	31	5.553		TURBULENT	Hard rock Gneiss	Possible large fracture within test zone accounts for high lugeon and permeability														
	14.8	2	10	240	240	143	30		0.972																		
	to	2	10	340	340	210	31		0.773																		
	16.8	2	10	240	240	137	29		0.931																		
		2	10	135	135	83	31		5.121																		
AVERAGE									2.670																		

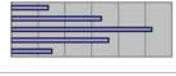


AMBATOVY PROJECT: TAILINGS DAM STUDY

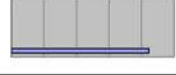
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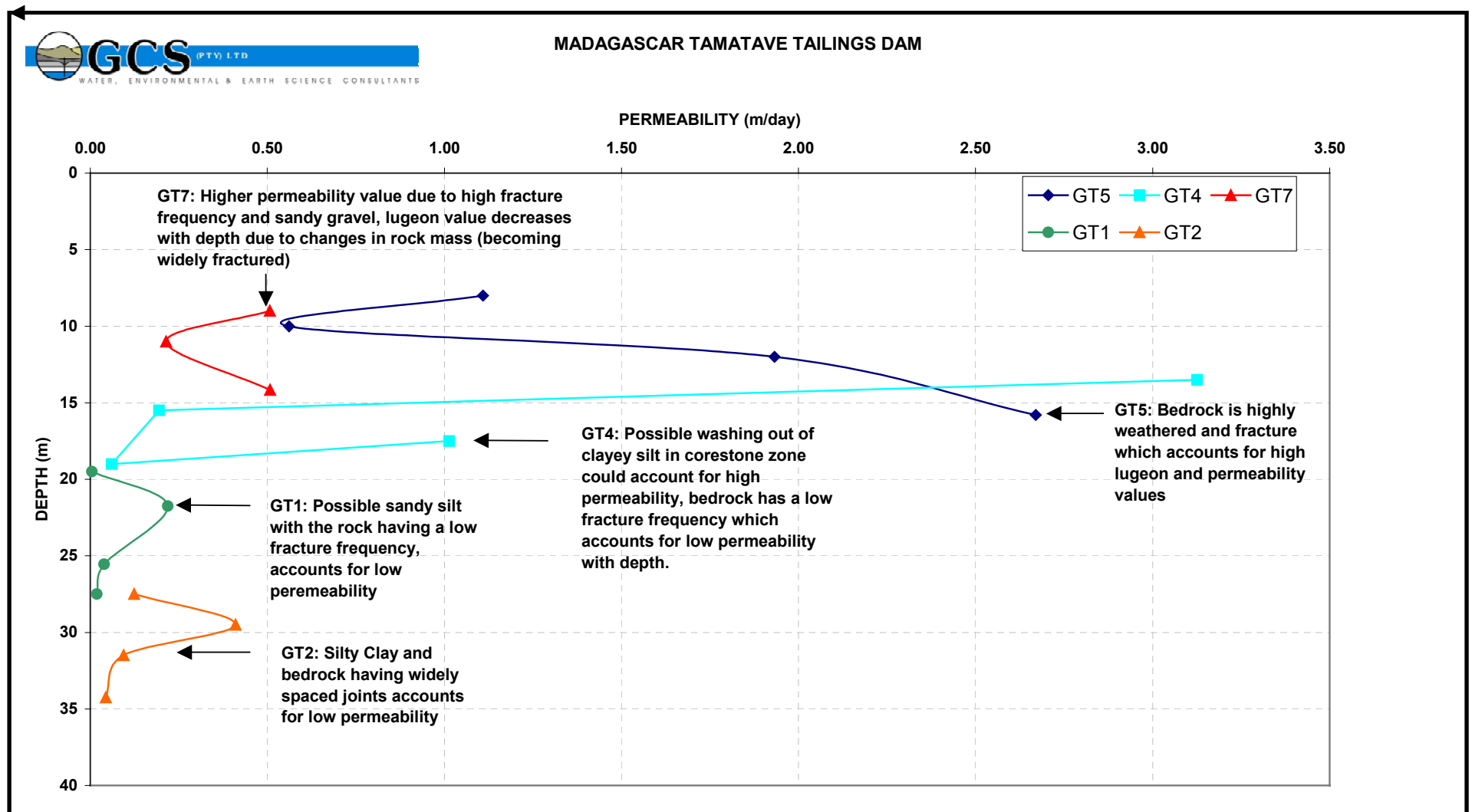
DATE	STAGES	TEST DEPTH (m)	TESTING TIME REQUIRED MINUTES	GAUGE PRESURES		WATER INTAKE LITRES	LUGEON VALUE		PERMEABILITY m/day	LUGEON PATTERN	PATTERN INTERPRETATION	GEOLOGY	COMMENT
	METERS			REQUIRED PRESURES	ACTUAL PRESURES		FOR EACH TEST	REPRESENTATIVE FOR EACH STAGE					
6-06-2004	from	2	10	70	70	24	17	12	0.332		DILATION	Sandy gravel to closely jointed Gneiss	High lugeon due to dilation and geology cannot account for low permeability.
	8	2	10	130	130	24	9		0.592				
	to	2	10	180	180	24	7		0.740				
	10	2	10	130	130	24	9		0.574				
		2	10	70	70	24	17		0.298				
									Average				

BOREHOLE: GT7B

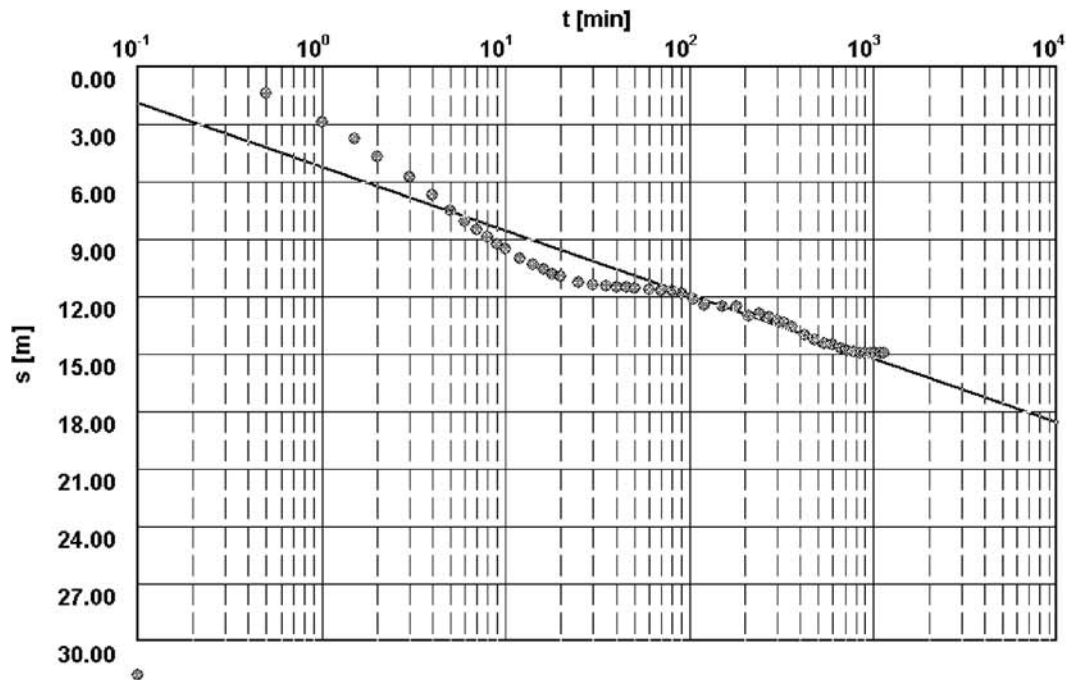
DATE	STAGES	TEST DEPTH (m)	TESTING TIME REQUIRED MINUTES	GAUGE PRESURES		WATER INTAKE LITRES	LUGEON VALUE		PERMEABILITY m/day	LUGEON PATTERN	PATTERN INTERPRETATION	GEOLOGY	COMMENT
	METERS			REQUIRED PRESURES	ACTUAL PRESURES		FOR EACH TEST	REPRESENTATIVE FOR EACH STAGE					
6-06-2004	from	2	10	90	90	90	50	16	0.107		DILATION	Closely jointed becoming widely jointed Gneiss	High lugeon value due to high fracture frequency
	10	2	10	160	160	21	7		0.256				
	to	2	10	225	225	21	5		0.374				
	12	2	10	160	160	21	7		0.236				
		2	10	90	90	21	12		0.098				
									Average				


BOREHOLE: GT7B

DATE	STAGES	TEST DEPTH (m)	TESTING TIME REQUIRED MINUTES	GAUGE PRESURES		WATER INTAKE LITRES	LUGEON VALUE		PERMEABILITY m/day	LUGEON PATTERN	PATTERN INTERPRETATION	GEOLOGY	COMMENT
	METERS			REQUIRED PRESURES	ACTUAL PRESURES		FOR EACH TEST	REPRESENTATIVE FOR EACH STAGE					
6-06-2004	from	4.31	10	110	110	1	0.21	0.04	0.511		INSUFFICIENT DATA	Widely jointed Gneiss	Low lugeon value due to low fracture frequency
	12	4.31	10	190	190	0	0		0.519				
	to	4.31	10	270	270	0	0		0.576				
	16.31	4.31	10	190	190	0	0		0.503				
		4.31	10	110	110	0	0		0.430				
									Average				

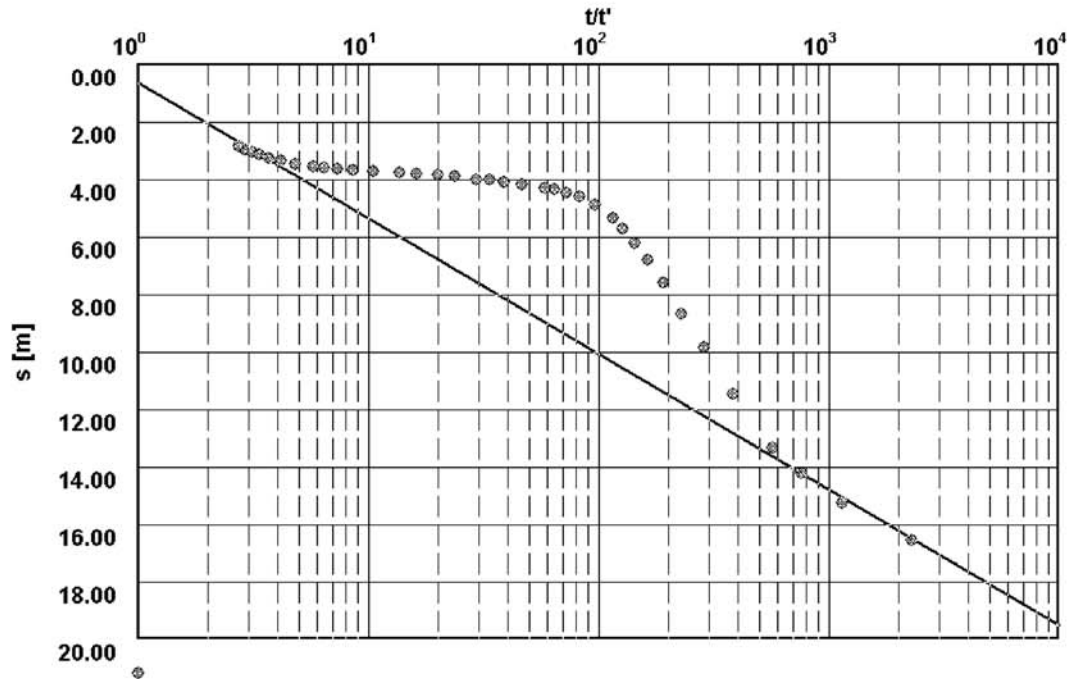



APPENDIX D: PUMPING TEST DATA

Borehole HG1: Constant Rate Test Data.

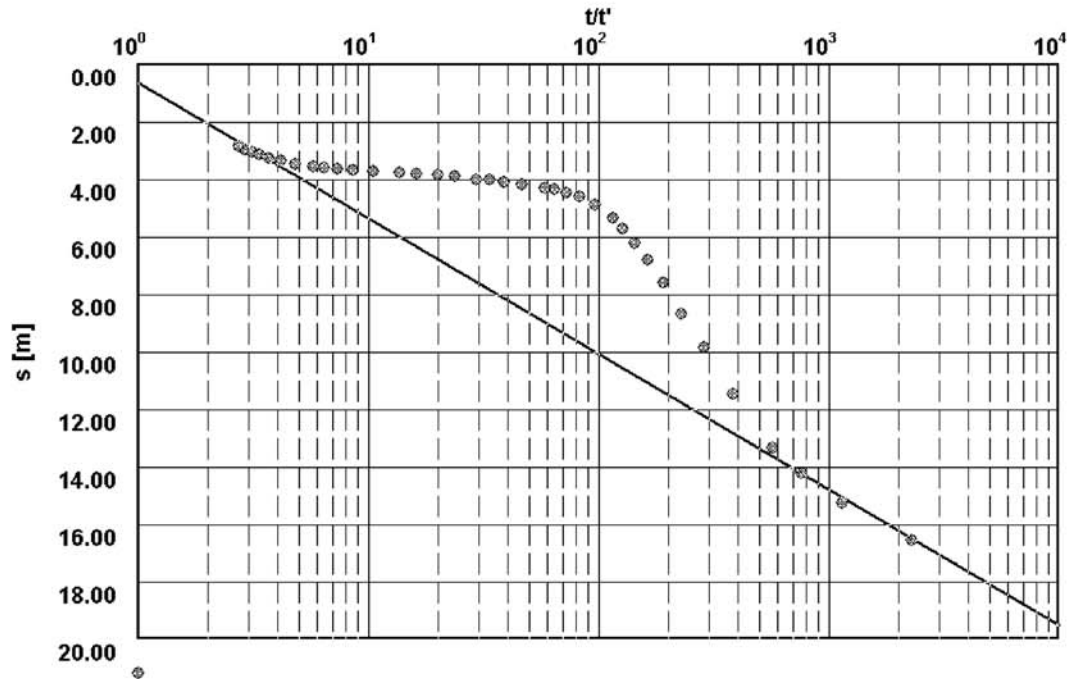
		Pumping Test Analysis Time-Drawdown Method after Cooper & Jacob			
		Discharge	2.24l/s	Date	15/07/2004
		SWL	6.42mbgl	Project	04.01-040
Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)
0.50	7.800	25.00	17.640	300.00	19.660
1.00	9.300	30.00	17.770	330.00	19.800
1.50	10.200	35.00	17.840	360.00	19.990
2.00	11.100	40.00	17.890	420.00	20.390
3.00	12.200	45.00	17.950	480.00	20.700
4.00	13.100	50.00	17.980	540.00	20.860
5.00	13.900	60.00	18.030	600.00	20.940
6.00	14.500	70.00	18.080	660.00	21.120
7.00	14.900	80.00	18.120	720.00	21.240
8.00	15.300	90.00	18.220	780.00	21.310
9.00	15.650	105.00	18.530	840.00	21.340
10.00	15.950	120.00	18.840	900.00	21.340
12.00	16.400	150.00	18.900	960.00	21.330
14.00	16.750	180.00	18.900	1020.00	21.340
16.00	17.000	210.00	19.400	1080.00	21.335
18.00	17.220	240.00	19.300	1140.00	21.340
20.00	17.380	270.00	19.510		


Borehole HG1: Recovery Data.



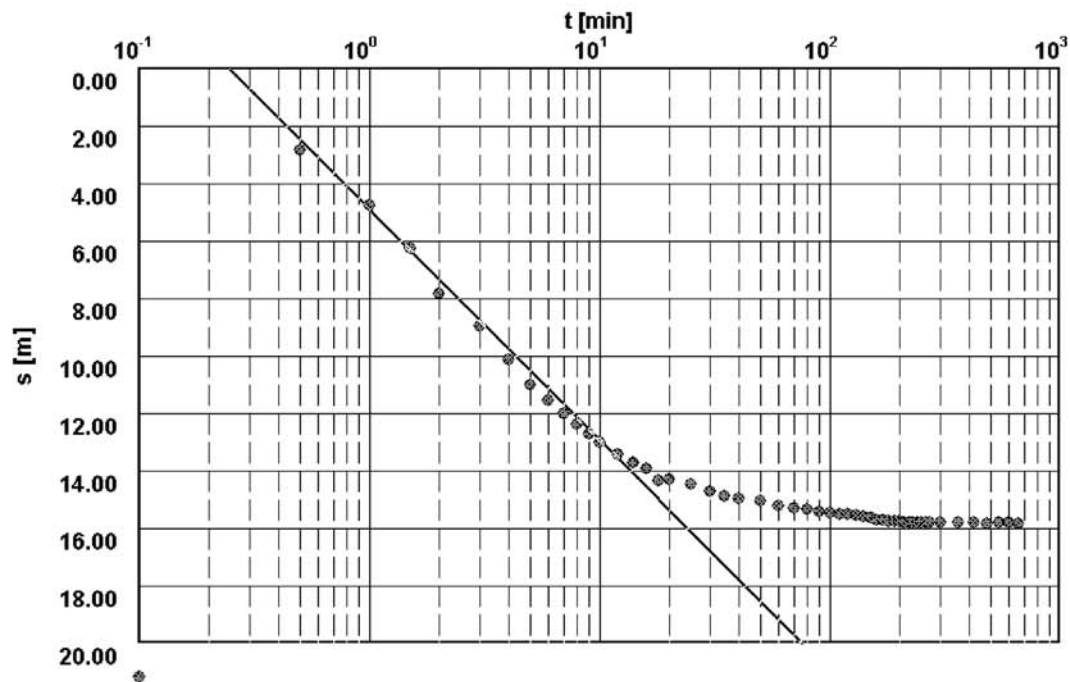
 GCS PTY. LTD. <small>WATER · ENVIRONMENTAL & EARTH SCIENCE CONSULTANTS</small>		Pumping Test Analysis Recovery Method after Theis & Jacob			
		Discharge	2.24l/s	Date	15/07/2004
		SWL	2.05mbd	Project	04.01-040
Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)
0.00	21.340	20.00	6.340	480.00	5.190
0.50	18.600	25.00	6.200	540.00	5.080
1.00	17.300	30.00	6.120	600.00	4.990
1.50	16.250	35.00	6.070	660.00	4.900
2.00	15.400	40.00	6.040		
3.00	13.500	50.00	5.940		
4.00	11.900	60.00	5.890		
5.00	10.700	75.00	5.840		
6.00	9.650	90.00	5.800		
7.00	8.850	120.00	5.770		
8.00	8.250	150.00	5.730		
9.00	7.750	180.00	5.690		
10.00	7.390	210.00	5.640		
12.00	6.920	240.00	5.590		
14.00	6.650	300.00	5.500		
16.00	6.500	360.00	5.390		
18.00	6.400	420.00	5.290		


Borehole HG1: Recovery Data.



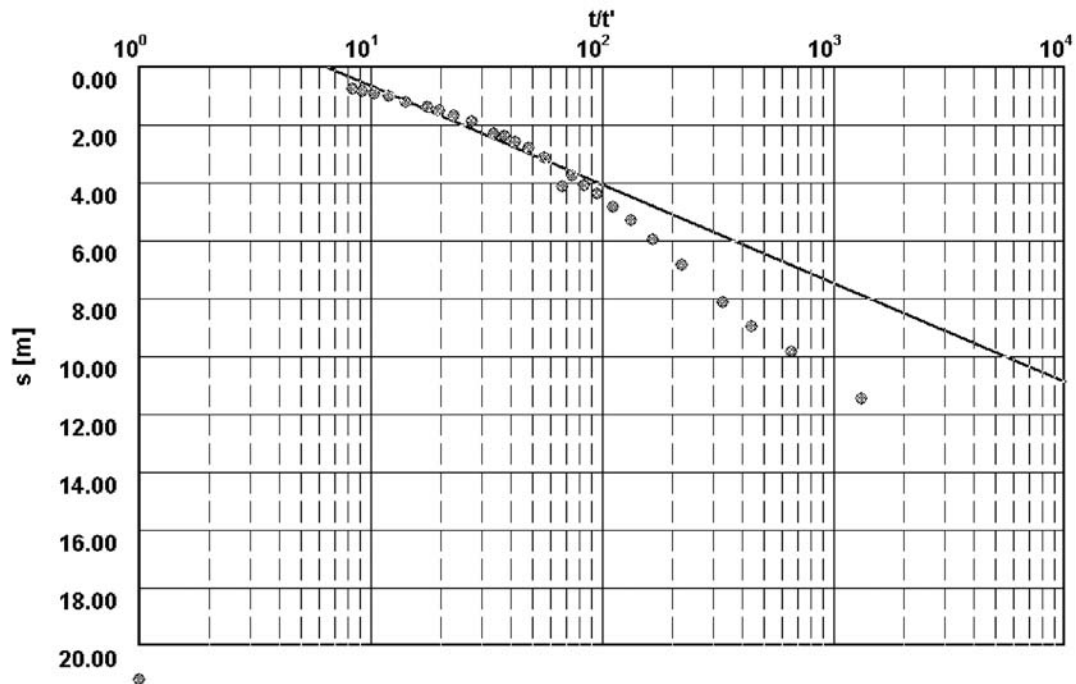
 GCS PTY LTD <small>WATER · ENVIRONMENTAL & EARTH SCIENCE CONSULTANTS</small>		Pumping Test Analysis Recovery Method after Theis & Jacob			
		Discharge	2.24l/s	Date	15/07/2004
		SWL	2.05mbd	Project	04.01-040
Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)
0.00	21.340	20.00	6.340	480.00	5.190
0.50	18.600	25.00	6.200	540.00	5.080
1.00	17.300	30.00	6.120	600.00	4.990
1.50	16.250	35.00	6.070	660.00	4.900
2.00	15.400	40.00	6.040		
3.00	13.500	50.00	5.940		
4.00	11.900	60.00	5.890		
5.00	10.700	75.00	5.840		
6.00	9.650	90.00	5.800		
7.00	8.850	120.00	5.770		
8.00	8.250	150.00	5.730		
9.00	7.750	180.00	5.690		
10.00	7.390	210.00	5.640		
12.00	6.920	240.00	5.590		
14.00	6.650	300.00	5.500		
16.00	6.500	360.00	5.390		
18.00	6.400	420.00	5.290		


Borehole HG2: Constant Rate Test Data.



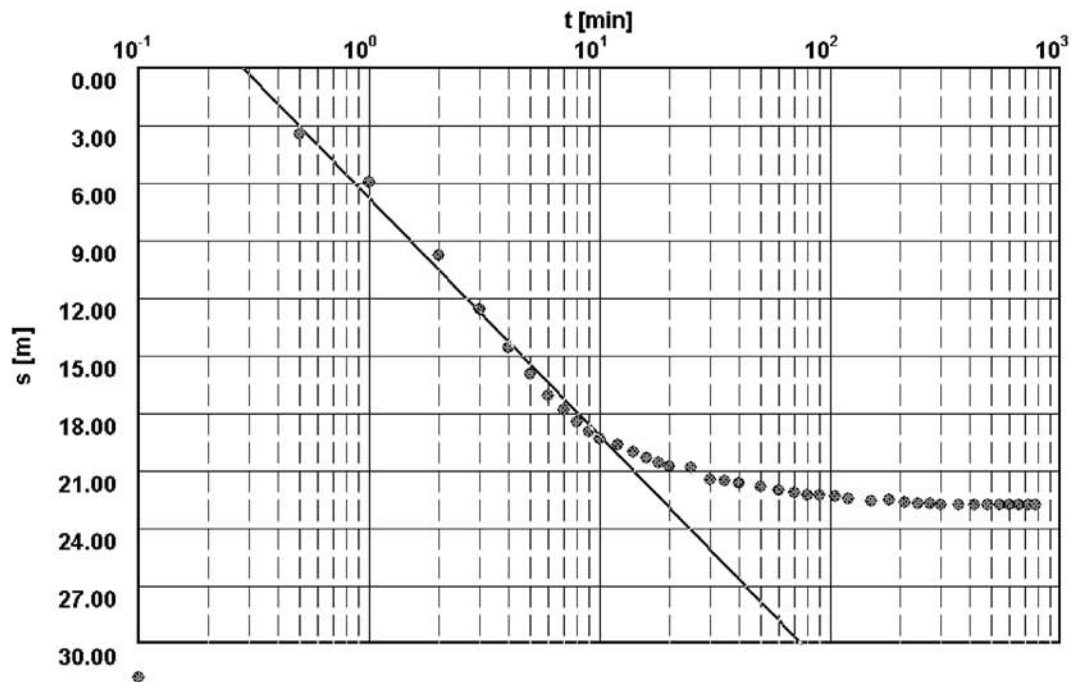
		Pumping Test Analysis Time-Drawdown Method after Cooper & Jacob			
		Discharge	2.80l/s	Date	15/07/2004
		SWL	5.56mbgl	Project	04.01-040
Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)
0.00	5.560	25.00	20.000	190.00	21.310
0.50	8.400	30.00	20.270	200.00	21.330
1.00	10.300	35.00	20.430	210.00	21.340
1.50	11.800	40.00	20.530	220.00	21.360
2.00	13.400	50.00	20.620	230.00	21.370
3.00	14.500	60.00	20.760	240.00	21.370
4.00	15.700	70.00	20.850	250.00	21.370
5.00	16.550	80.00	20.910	260.00	21.370
6.00	17.120	90.00	20.960	270.00	21.370
7.00	17.550	100.00	21.020	300.00	21.370
8.00	17.950	110.00	21.040	360.00	21.370
9.00	18.270	120.00	21.060	420.00	21.370
10.00	18.550	130.00	21.090	480.00	21.380
12.00	18.970	140.00	21.130	540.00	21.370
14.00	19.260	150.00	21.190	600.00	21.370
16.00	19.490	160.00	21.250	660.00	21.380
18.00	19.880	170.00	21.280		
20.00	19.840	180.00	21.290		


Borehole HG2: Recovery Data.



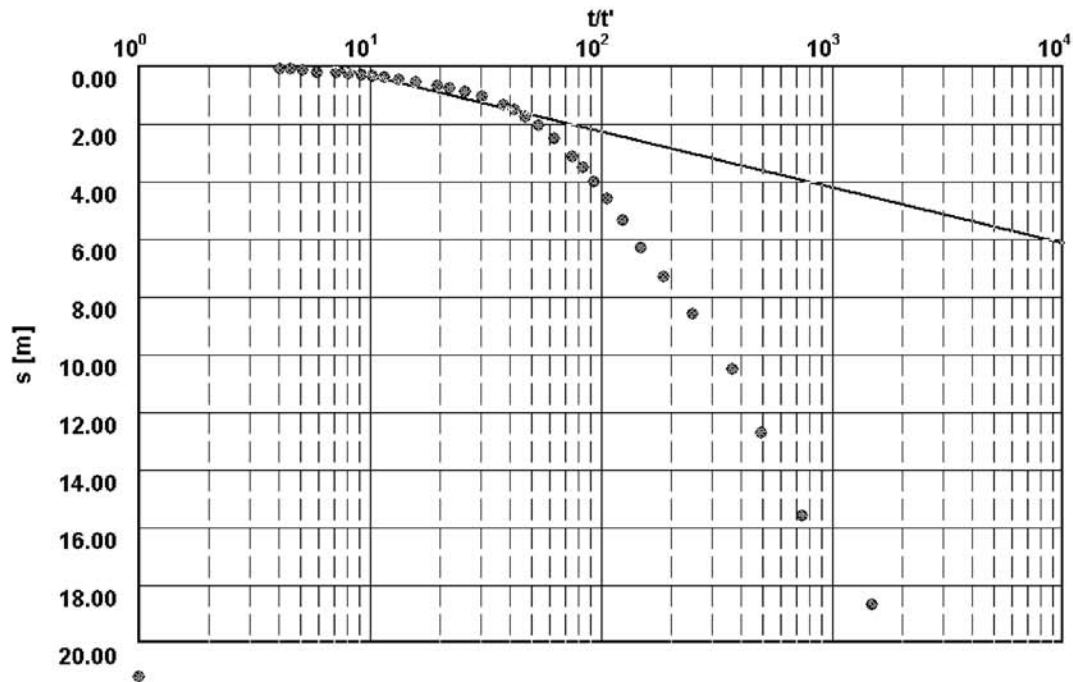
		Pumping Test Analysis			
		Recovery Method after Theis & Jacob			
		Discharge	2.80l/s	Date	15/07/2004
		SWL	5.56mbd	Project	04.01-040
Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)
0.00	21.370	7.00	9.950	25.00	7.440
0.50	17.010	8.00	9.650	30.00	7.220
1.00	15.400	9.00	9.330	35.00	7.070
1.50	14.500	10.00	9.680	40.00	6.920
2.00	13.700	12.00	8.680	50.00	6.750
3.00	12.400	14.00	8.370	60.00	6.570
4.00	11.520	16.00	8.130	70.00	6.460
5.00	10.860	18.00	7.920	80.00	6.380
6.00	10.380	20.00	7.860	90.00	6.330


Borehole HG3: Constant Rate Test Data.

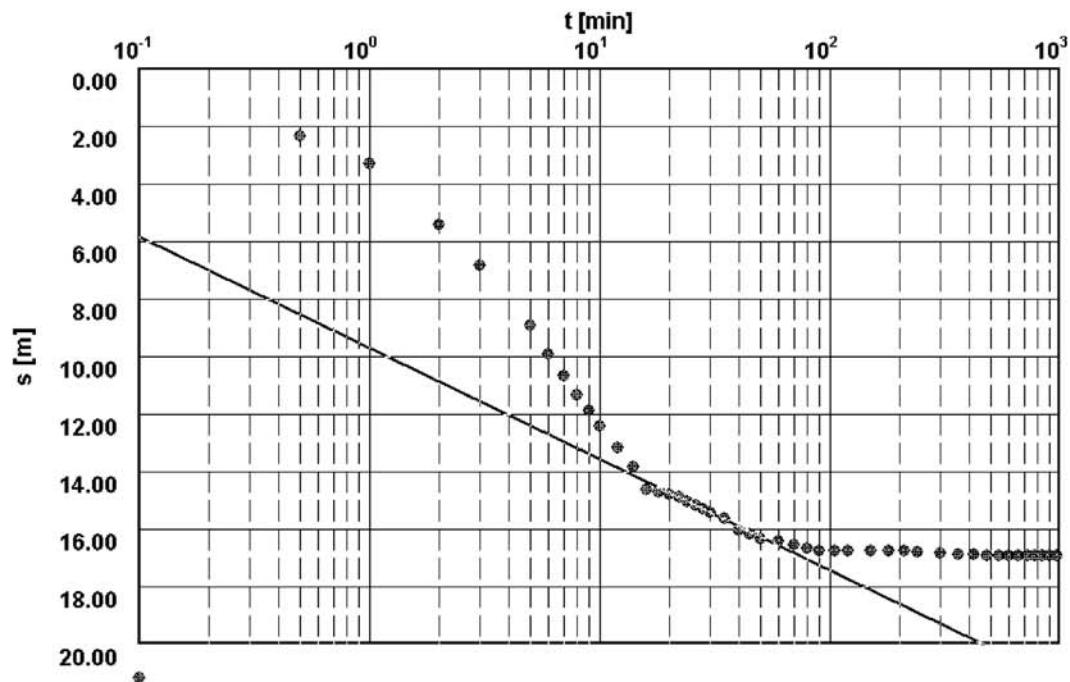



		Pumping Test Analysis Time-Drawdown Method after Cooper & Jacob			
		Discharge	2.89l/s	Date	15/07/2004
		SWL	2.76mbgl	Project	04.01-040
Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)
0.00	2.760	16.00	23.100	150.00	25.340
0.50	6.200	18.00	23.300	180.00	25.260
1.00	8.700	20.00	23.480	210.00	25.370
2.00	12.500	25.00	23.560	240.00	25.450
3.00	15.300	30.00	24.180	270.00	25.470
4.00	17.300	35.00	24.290	300.00	25.490
5.00	18.700	40.00	24.410	360.00	25.510
6.00	19.800	50.00	24.580	420.00	25.510
7.00	20.550	60.00	24.730	480.00	25.520
8.00	21.200	70.00	24.880	540.00	25.530
9.00	21.700	80.00	24.980	600.00	25.530
10.00	22.050	90.00	25.010	660.00	25.530
12.00	22.400	105.00	25.090	720.00	25.530
14.00	22.750	120.00	25.220	780.00	25.530

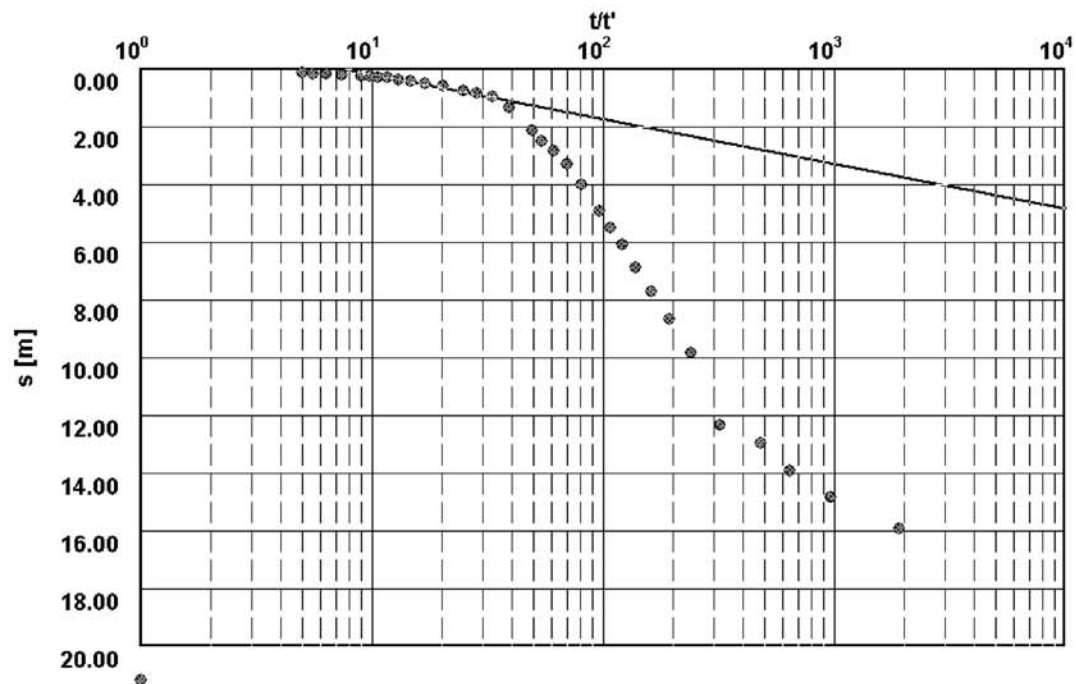
Borehole HG3: Recovery Data.




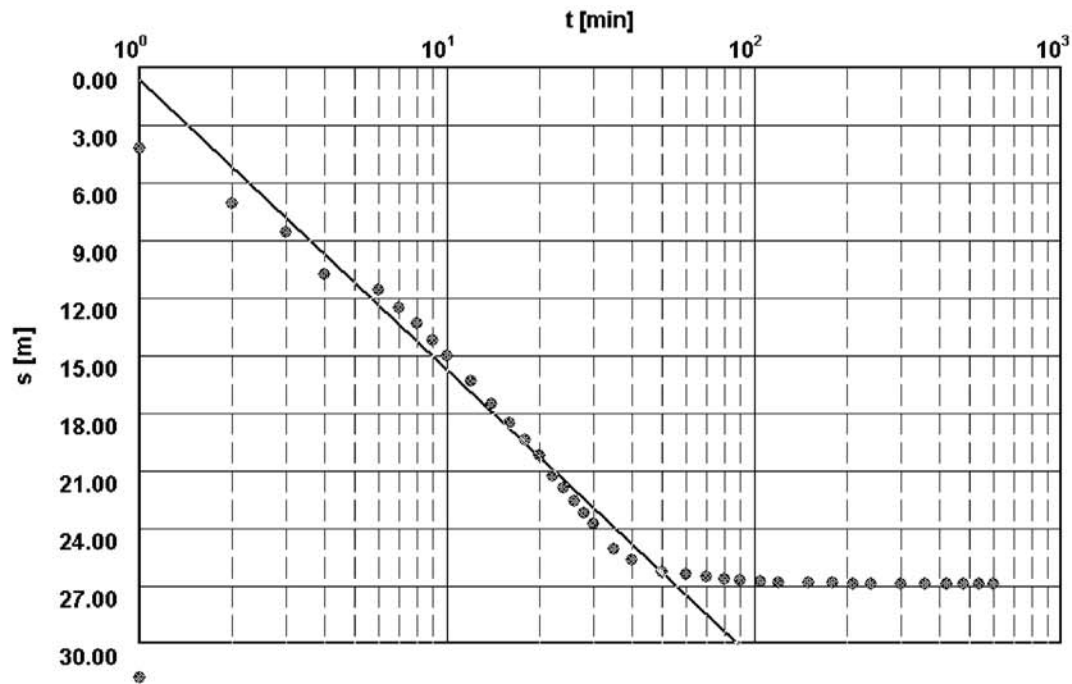
 GCS PTY LTD <small>WATER, ENVIRONMENTAL & EARTH SCIENCE CONSULTANTS</small>		Pumping Test Analysis Recovery Method after Theis & Jacob			
		Discharge	2.89l/s	Date	15/07/2004
		SWL	2.76mbd	Project	04.01-040
Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)
0.00	25.530	9.00	6.270	50.00	3.300
0.50	21.420	10.00	5.870	60.00	3.210
1.00	18.350	12.00	5.240	70.00	3.140
1.50	15.450	14.00	4.800	80.00	3.090
2.00	13.250	16.00	4.500	90.00	3.040
3.00	11.350	18.00	4.280	105.00	3.000
4.00	10.050	20.00	4.090	120.00	2.960
5.00	9.040	25.00	3.820	150.00	2.950
6.00	8.080	30.00	3.650	180.00	2.900
7.00	7.360	35.00	3.530	210.00	2.860
8.00	6.760	40.00	3.440	240.00	2.840


Borehole HG4: Constant Rate Test Data.

		Pumping Test Analysis Time-Drawdown Method after Cooper & Jacob			
		Discharge	1.44l/s	Date	15/07/2004
		SWL	13.57mbgl	Project	04.01-040
Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)
0.00	13.510	22.00	28.430	180.00	30.310
0.50	15.900	24.00	28.610	210.00	30.320
1.00	16.850	26.00	28.750	240.00	30.370
2.00	19.000	28.00	28.880	300.00	30.395
3.00	20.400	30.00	29.000	360.00	30.430
5.00	22.500	35.00	29.210	420.00	30.460
6.00	23.500	40.00	29.630	480.00	30.490
7.00	24.250	45.00	29.750	540.00	30.500
8.00	24.900	50.00	29.910	600.00	30.500
9.00	25.450	60.00	30.000	660.00	30.505
10.00	25.970	70.00	30.100	720.00	30.500
12.00	26.730	80.00	30.240	780.00	30.505
14.00	27.400	90.00	30.300	840.00	30.500
16.00	28.180	105.00	30.310	900.00	30.500
18.00	28.290	120.00	30.310	960.00	30.500
20.00	28.370	150.00	30.310		

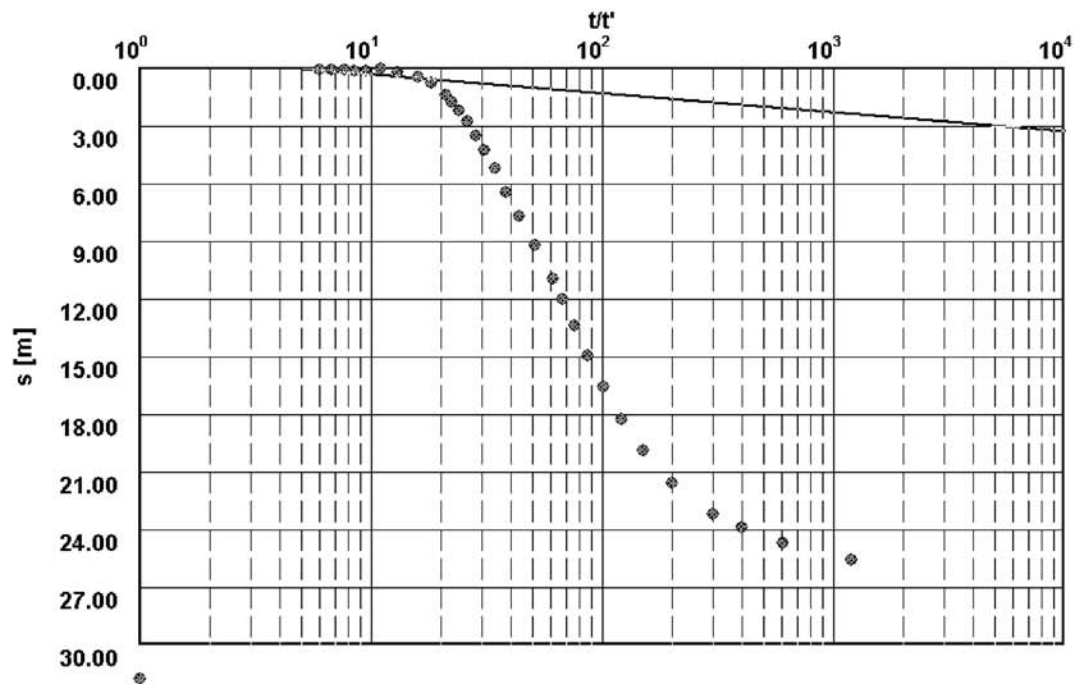
Borehole HG4: Recovery Data.


 GCS PTY LTD <small>WATER, ENVIRONMENTAL & EARTH SCIENCE CONSULTANTS</small>		Pumping Test Analysis Recovery Method after Theis & Jacob			
		Discharge	1.44l/s	Date	15/07/2004
		SWL	13.51mbd	Project	04.01-040
Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)
0.00	30.500	10.00	18.410	70.00	13.920
0.50	29.420	12.00	17.510	80.00	13.870
1.00	28.330	14.00	16.810	90.00	13.820
1.50	27.410	16.00	16.350	100.00	13.800
2.00	26.470	18.00	16.000	110.00	13.770
3.00	25.860	20.00	15.650	120.00	13.740
4.00	23.360	25.00	14.850	150.00	13.710
5.00	22.170	30.00	14.460	180.00	13.680
6.00	21.210	35.00	14.340	210.00	13.660
7.00	20.400	40.00	14.250	240.00	13.640
8.00	19.610	50.00	14.100		
9.00	18.990	60.00	14.010		

Borehole HG5: Constant Rate Test Data.

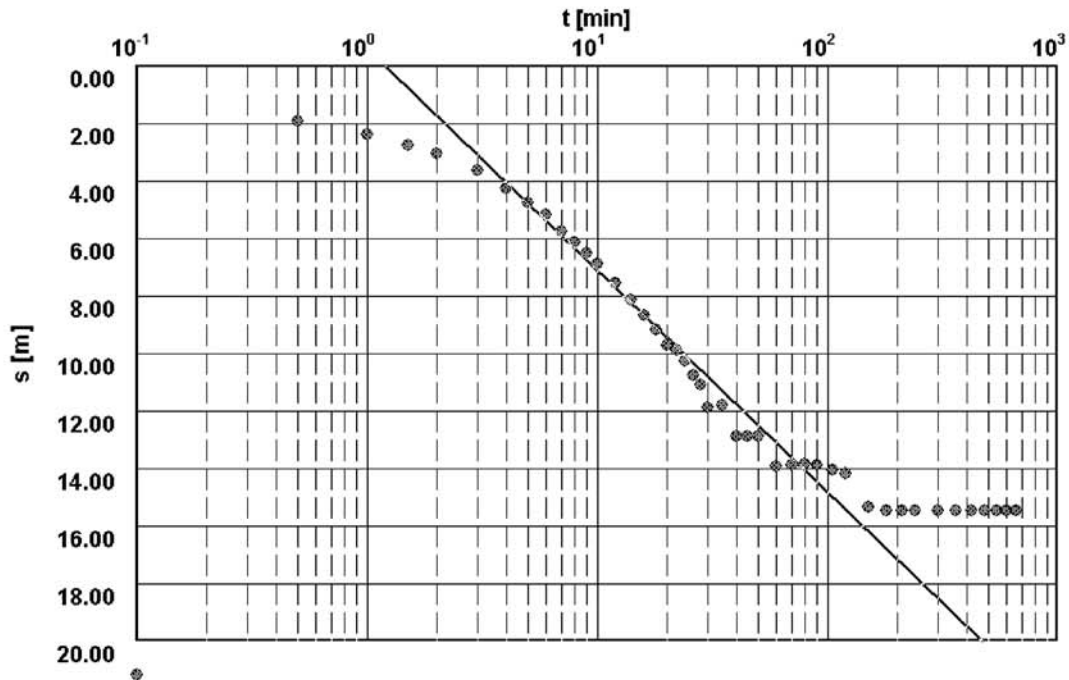
 GCS PTY LTD <small>WATER, ENVIRONMENTAL & EARTH SCIENCE CONSULTANTS</small>		Pumping Test Analysis Time-Drawdown Method after Cooper & Jacob			
		Discharge	0.94l/s	Date	15/07/2004
		SWL	2.84mbgl	Project	04.01-040
Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)
0.00	2.840	18.00	22.220	90.00	29.540
1.00	7.000	20.00	23.040	105.00	29.600
2.00	9.910	22.00	24.070	120.00	29.630
3.00	11.410	24.00	24.710	150.00	29.670
4.00	13.570	26.00	25.420	180.00	29.680
6.00	14.420	28.00	26.020	210.00	29.690
7.00	15.330	30.00	26.610	240.00	29.700
8.00	16.160	35.00	27.910	300.00	29.700
9.00	17.040	40.00	28.490	360.00	29.700
10.00	17.810	50.00	29.070	420.00	29.710
12.00	19.170	60.00	29.210	480.00	29.710
14.00	20.310	70.00	29.370	540.00	29.710
16.00	21.330	80.00	29.470	600.00	29.700


Borehole HG5: Recovery Data.



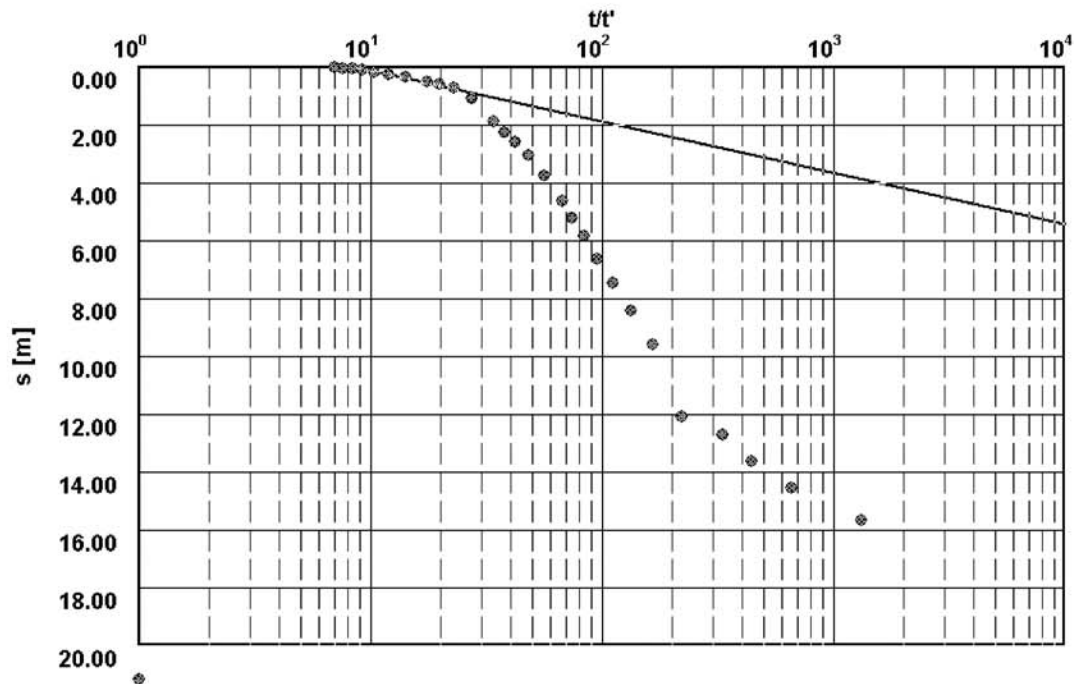
 GCS PTY LTD <small>WATER, ENVIRONMENTAL & EARTH SCIENCE CONSULTANTS</small>		Pumping Test Analysis Recovery Method after Theis & Jacob			
		Discharge	0.94l/s	Date	15/07/2004
		SWL	2.84mbd	Project	04.01-040
Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)
0.00	29.700	9.00	14.830	30.00	4.220
0.50	28.400	10.00	13.800	35.00	3.600
1.00	27.500	12.00	12.000	40.00	3.270
1.50	26.700	14.00	10.500	50.00	3.050
2.00	26.000	16.00	9.250	60.00	2.870
3.00	24.400	18.00	8.000	70.00	2.950
4.00	22.700	20.00	7.120	80.00	2.940
5.00	21.100	22.00	6.310	90.00	2.920
6.00	19.400	24.00	5.620	105.00	2.910
7.00	17.800	26.00	5.050	120.00	2.890
8.00	16.200	28.00	4.600		


Borehole HG6: Constant Rate Test Data.



		Pumping Test Analysis Time-Drawdown Method after Cooper & Jacob			
		Discharge	0.31l/s	Date	15/07/2004
		SWL	13.77mbgl	Project	04.01-040
Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)
0.00	13.770	16.00	22.450	90.00	27.660
0.50	15.700	18.00	22.950	105.00	27.820
1.00	16.130	20.00	23.480	120.00	27.920
1.50	16.500	22.00	23.660	150.00	29.090
2.00	16.800	24.00	24.000	180.00	29.220
3.00	17.400	26.00	24.530	210.00	29.230
4.00	18.000	28.00	24.850	240.00	29.230
5.00	18.500	30.00	25.650	300.00	29.230
6.00	18.950	35.00	25.580	360.00	29.230
7.00	19.500	40.00	26.640	420.00	29.240
8.00	19.900	45.00	26.650	480.00	29.230
9.00	20.250	50.00	26.650	540.00	29.240
10.00	20.650	60.00	27.670	600.00	29.240
12.00	21.300	70.00	27.650	660.00	29.240
14.00	21.900	80.00	27.620		

Borehole HG6: Recovery Data.



		Pumping Test Analysis Recovery Method after Theis & Jacob			
		Discharge	0.31l/s	Date	15/07/2004
		SWL	13.77mbd	Project	04.01-040
Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)	Time (min)	Water Level (mbgl)
0.00	30.500	10.00	18.410	70.00	13.920
0.50	29.420	12.00	17.510	80.00	13.870
1.00	28.330	14.00	16.810	90.00	13.820
1.50	27.410	16.00	16.350	100.00	13.800
2.00	26.470	18.00	16.000	110.00	13.770
3.00	25.860	20.00	15.650	120.00	13.740
4.00	23.360	25.00	14.850	150.00	13.710
5.00	22.170	30.00	14.460	180.00	13.680
6.00	21.210	35.00	14.340	210.00	13.660
7.00	20.400	40.00	14.250	240.00	13.640
8.00	19.610	50.00	14.100		
9.00	18.990	60.00	14.010		

APPENDIX E: SEEPAGE ANALYSIS

FIGURES

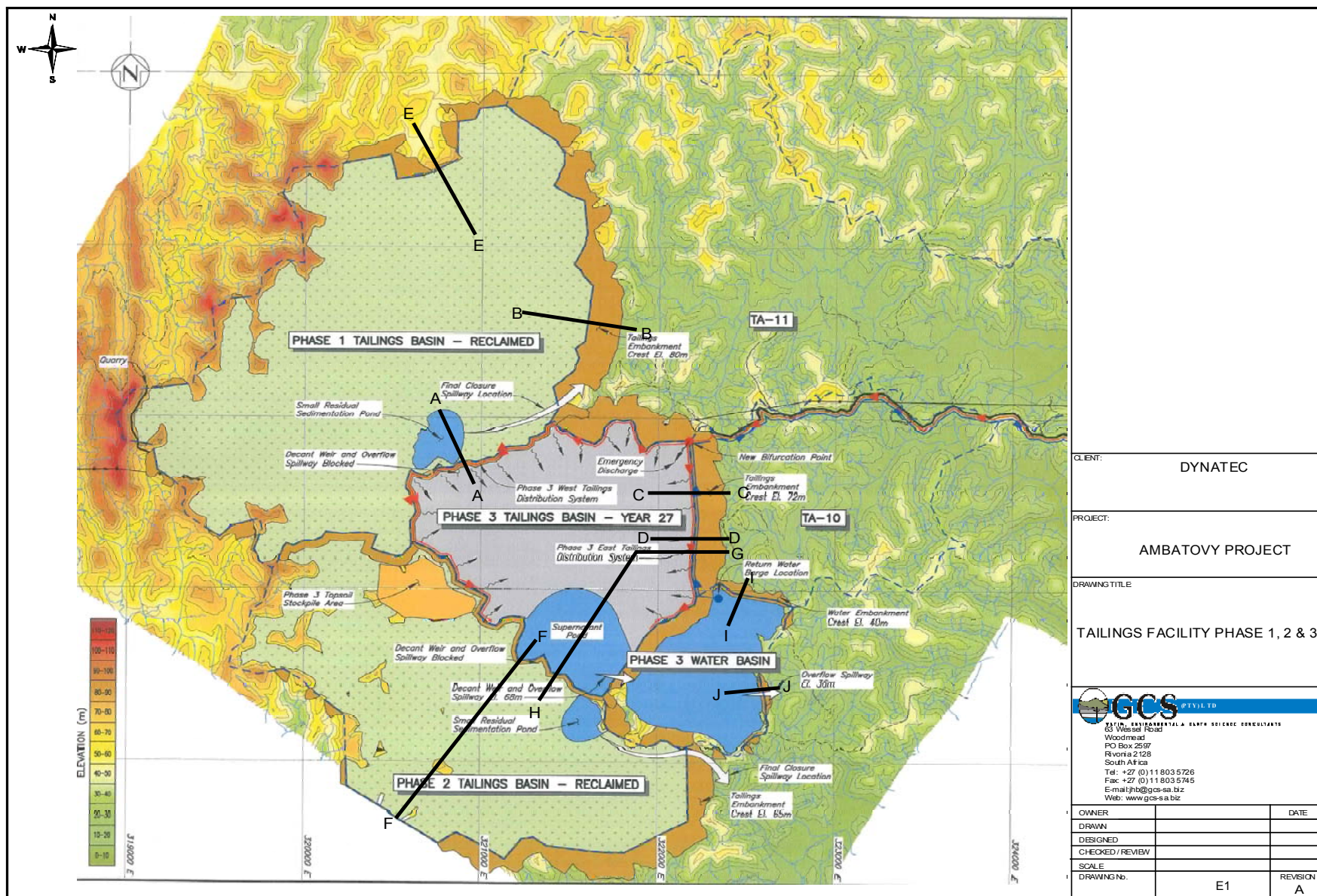


Figure E1: Tailings Storage Facility General Arrangement.

Figure E2: Tailings Basin – Phase 1, Year 1.

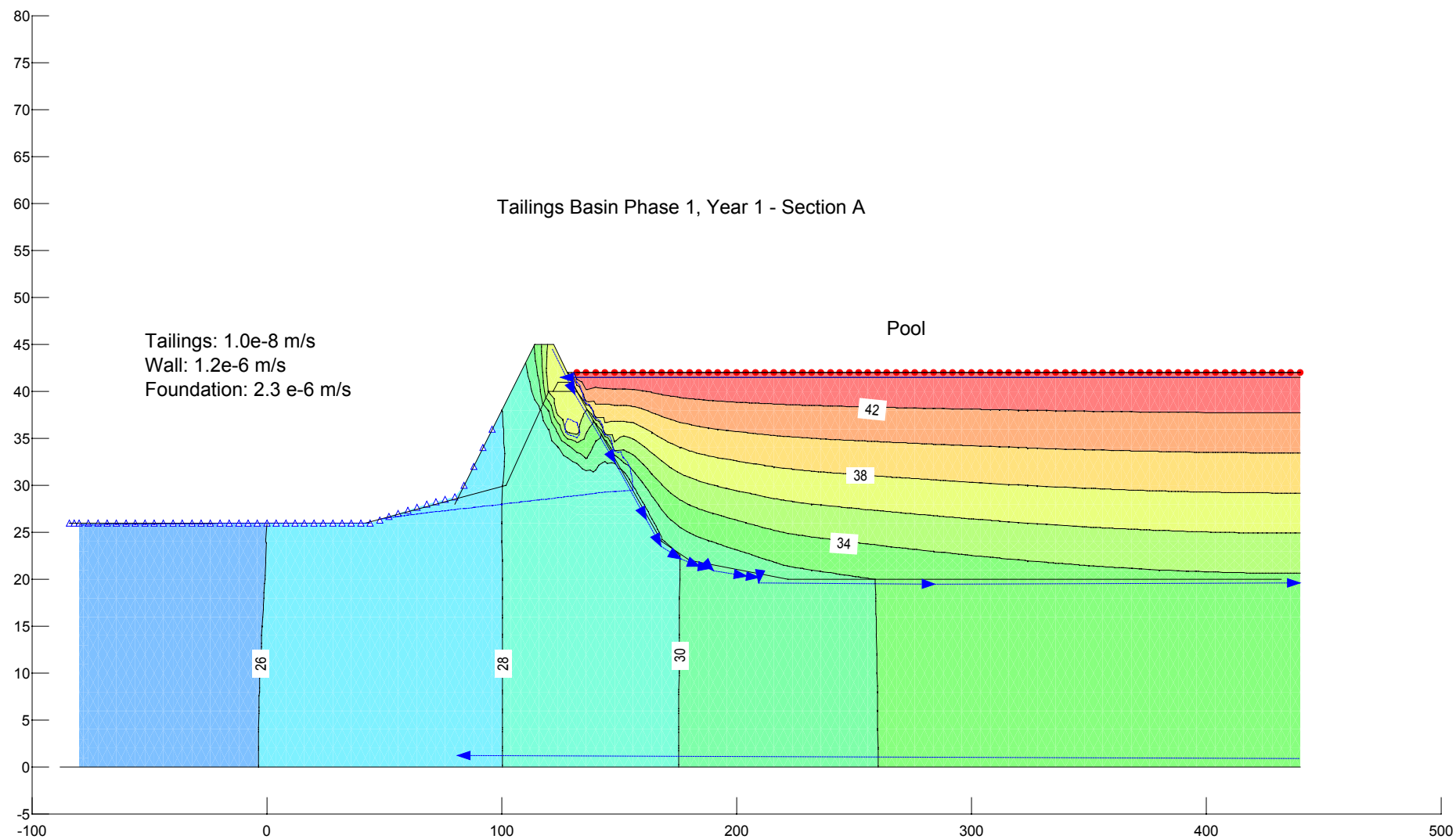


Figure E3: Tailings Basin – Phase 1, Year 1

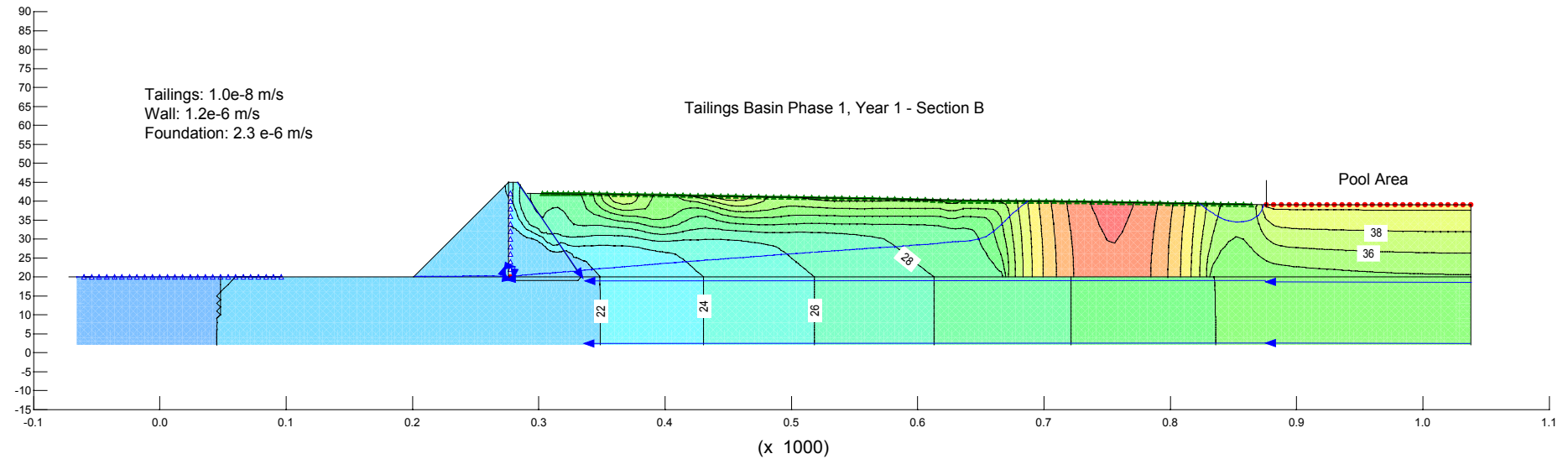


Figure E4: Tailings Basin – Phase 1, Year 1

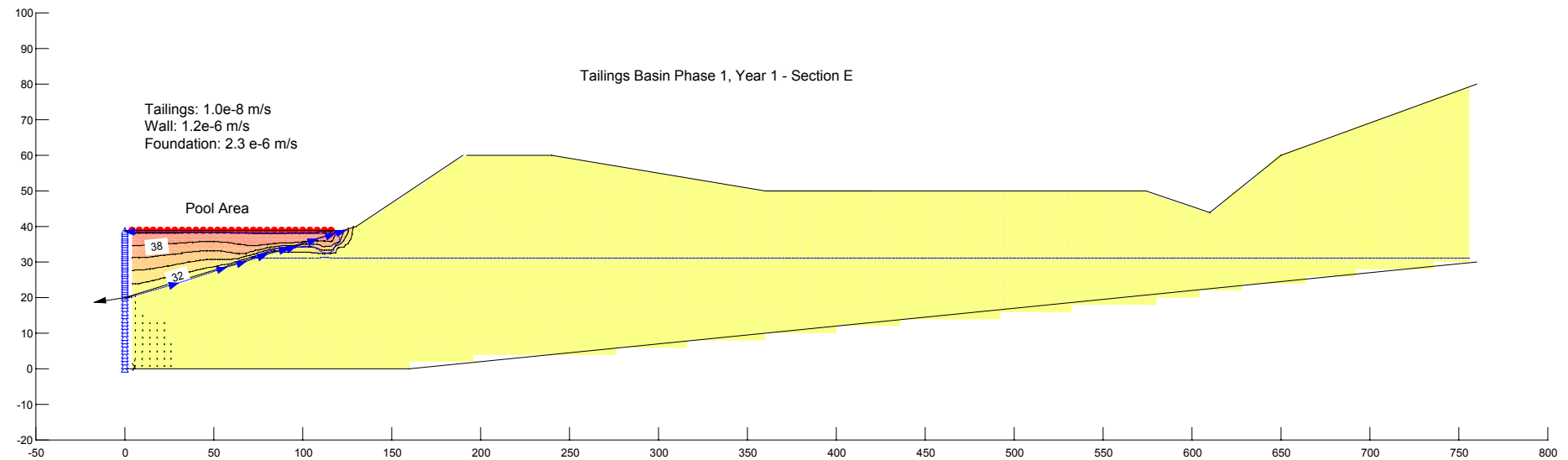


Figure E5: Tailings Basin – Phase 1, 14 Years.

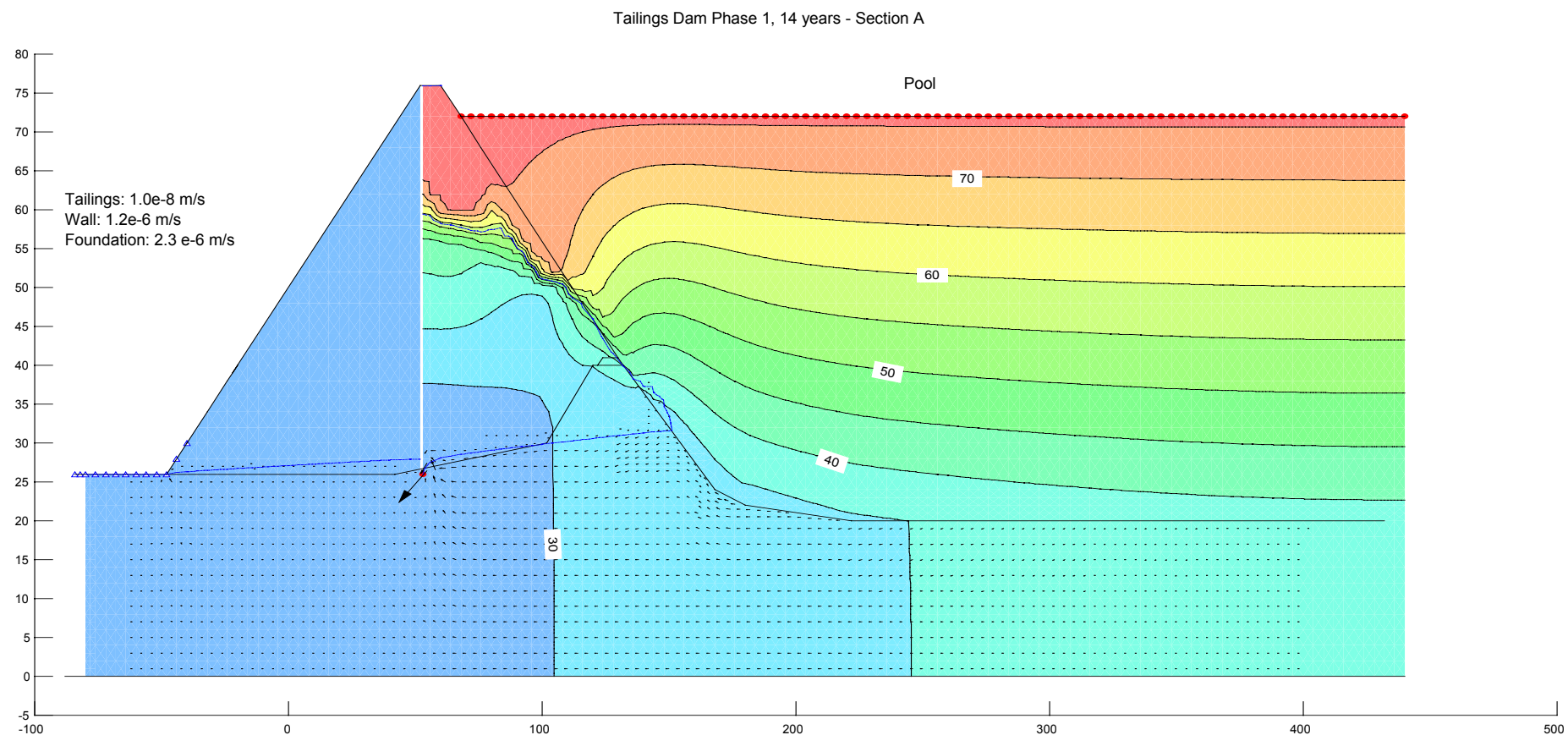


Figure E6: Tailings Basin – Phase 1, 14 Years.

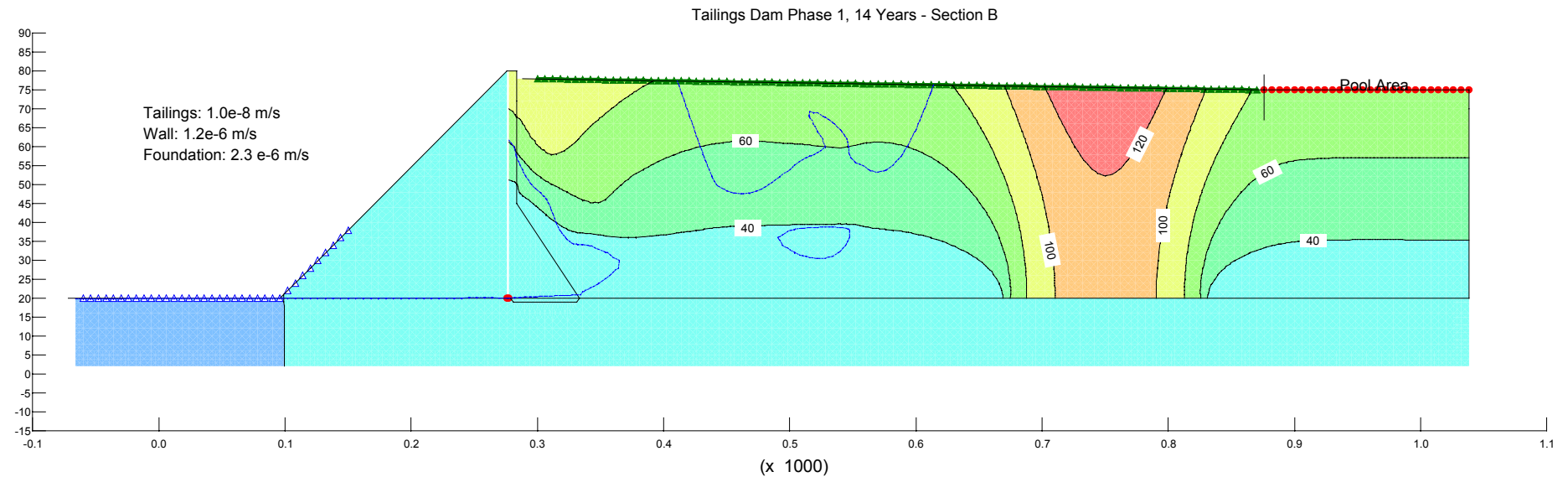


Figure E7: Tailings Basin – Phase 1, 14 Years

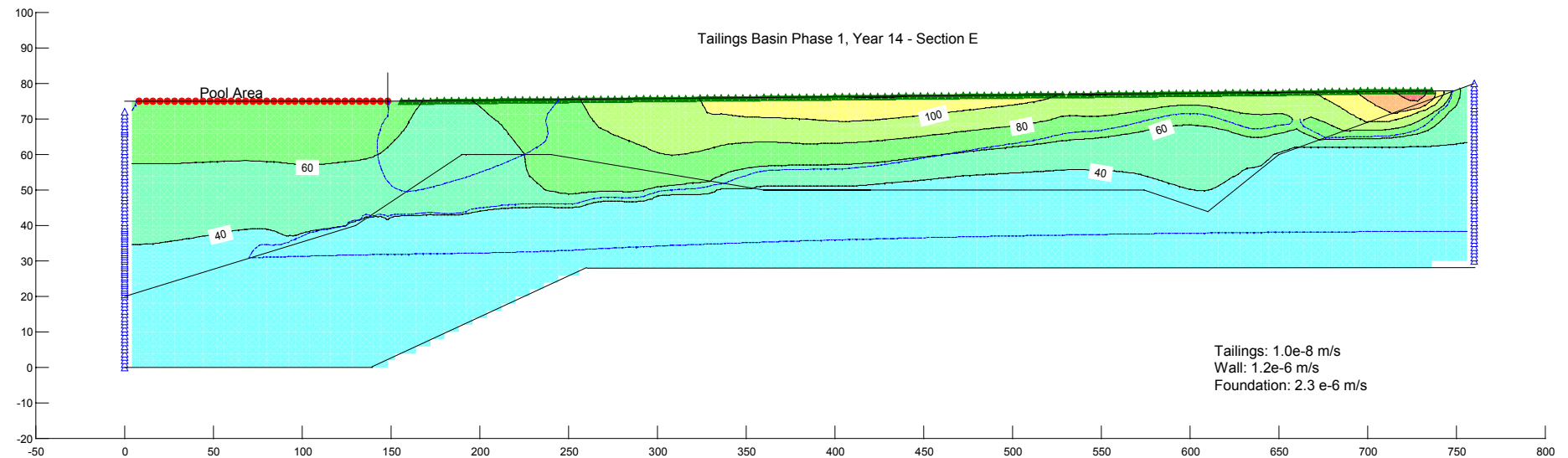


Figure E8: Tailings Basin – Phase 2, 20.5 Years.

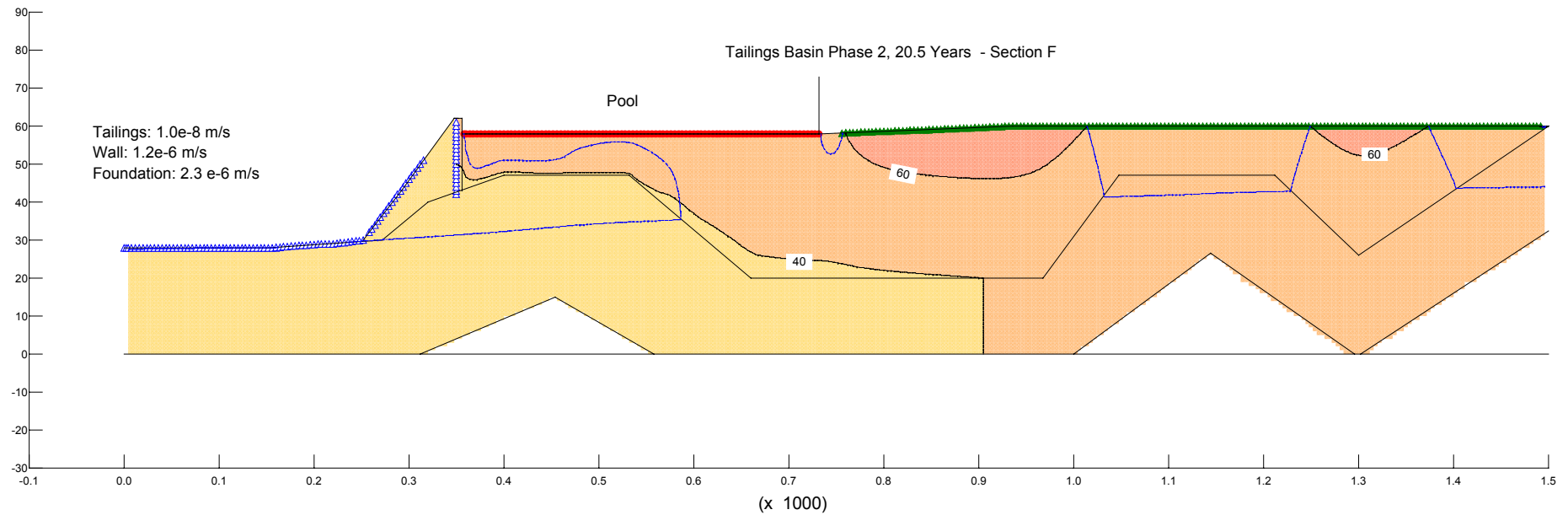


Figure E9: Tailings Basin – Phase 3, 27 Years.

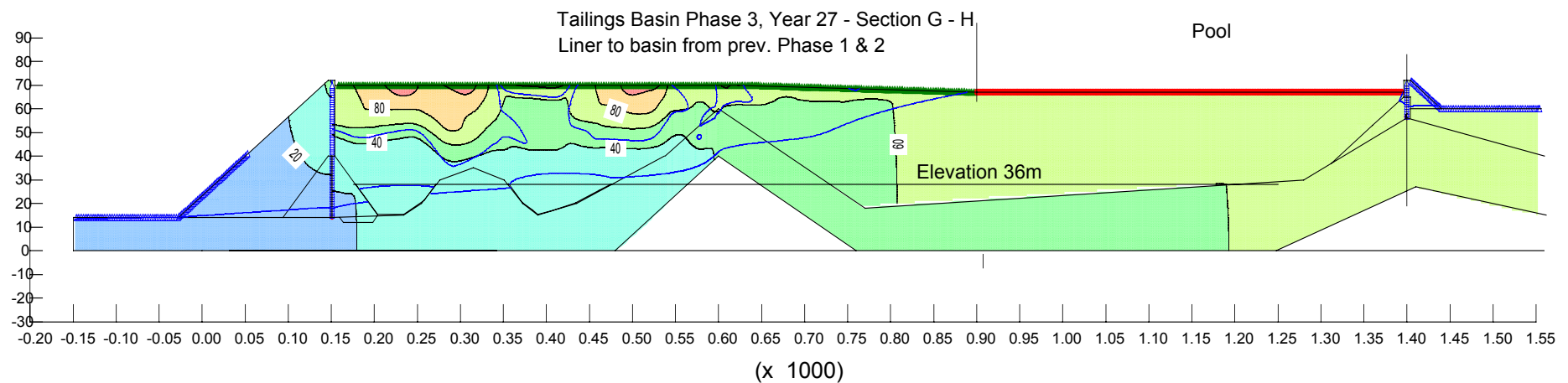


Figure E10: Tailings Basin – Phase 3, 27 Years.

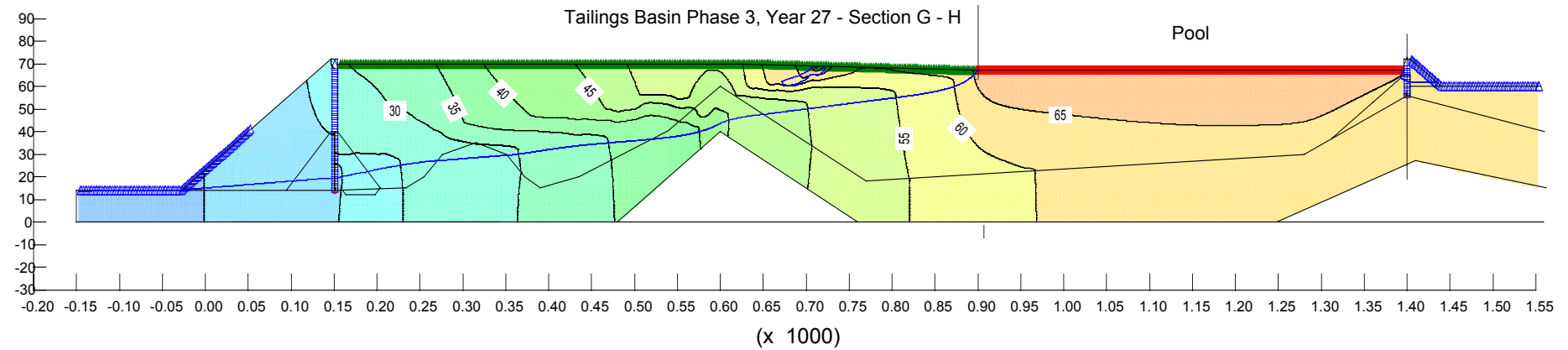


Figure E11: Water Basin – Phase 1 & 2.

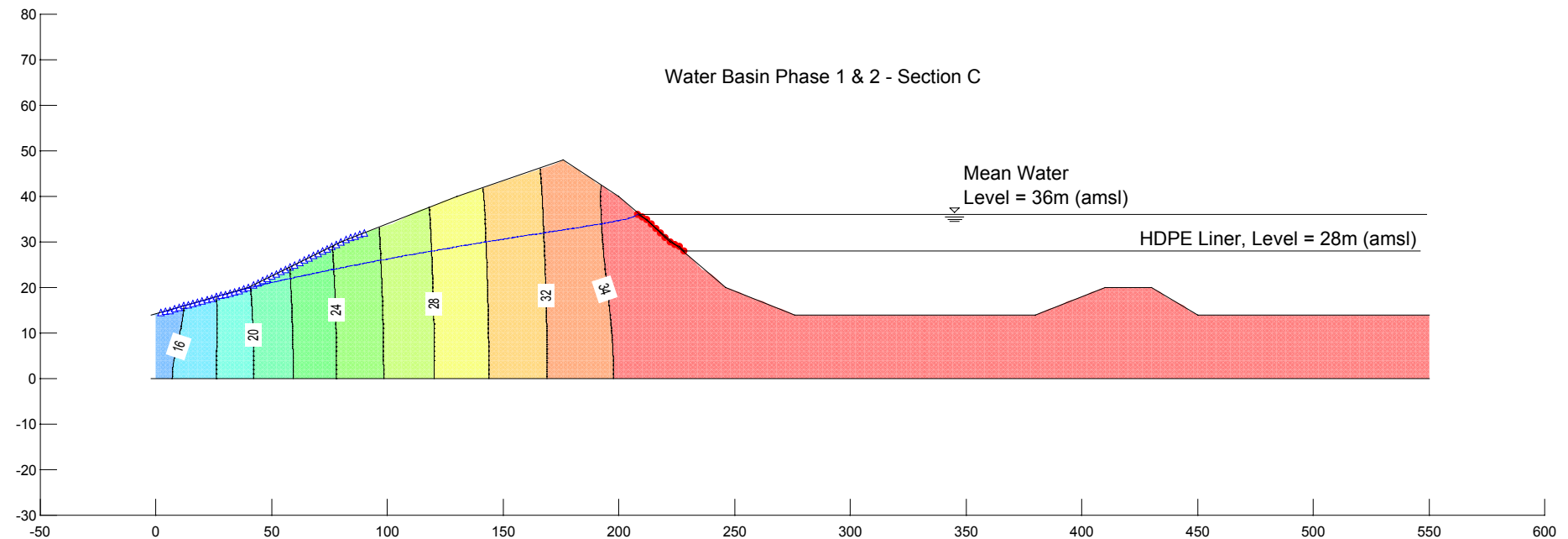


Figure E12: Water Basin – Phase 1 & 2.

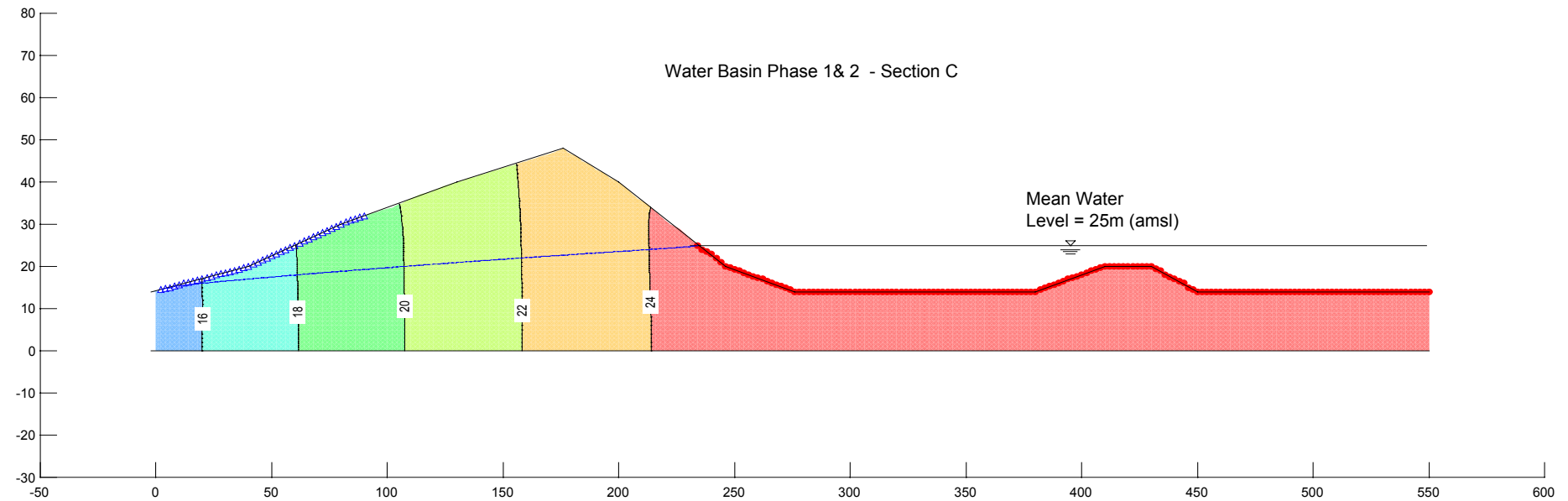


Figure E13: Water Basin – Phase 1 & 2.

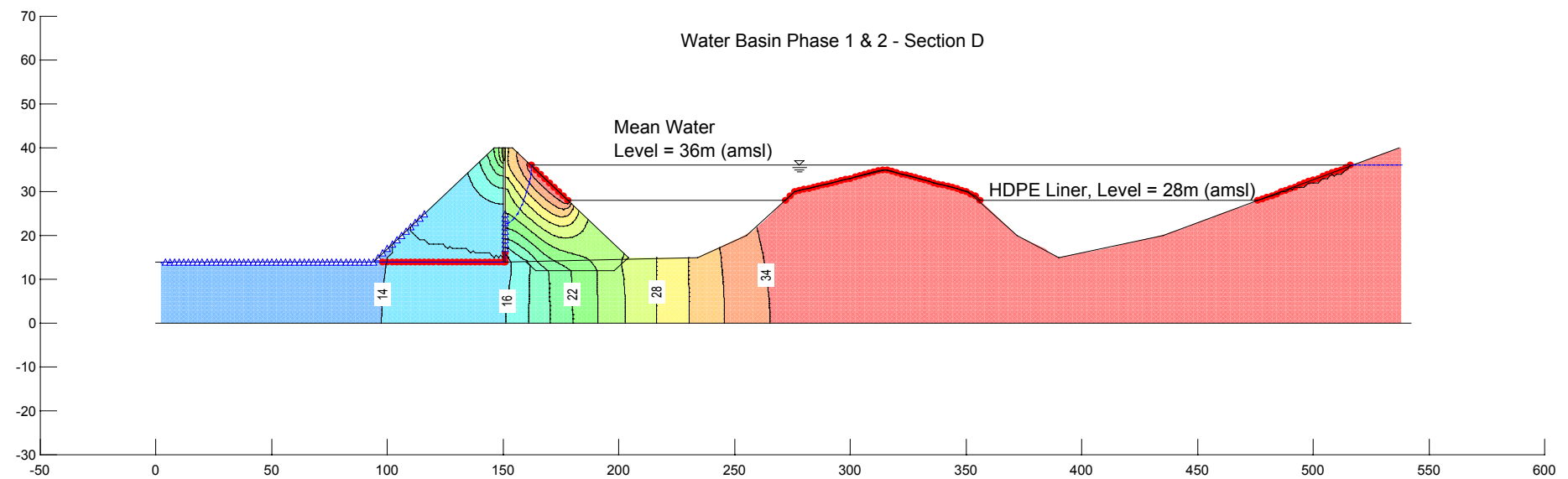


Figure E14: Water Basin – Phase 1 & 2.

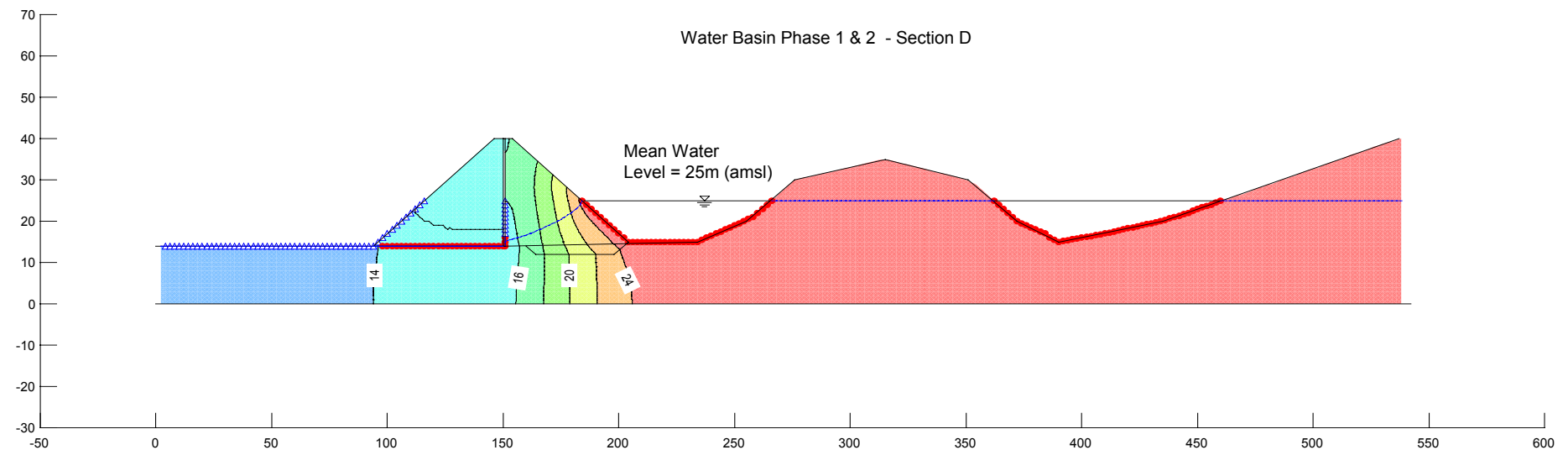


Figure E15: Water Basin – Phase 3.

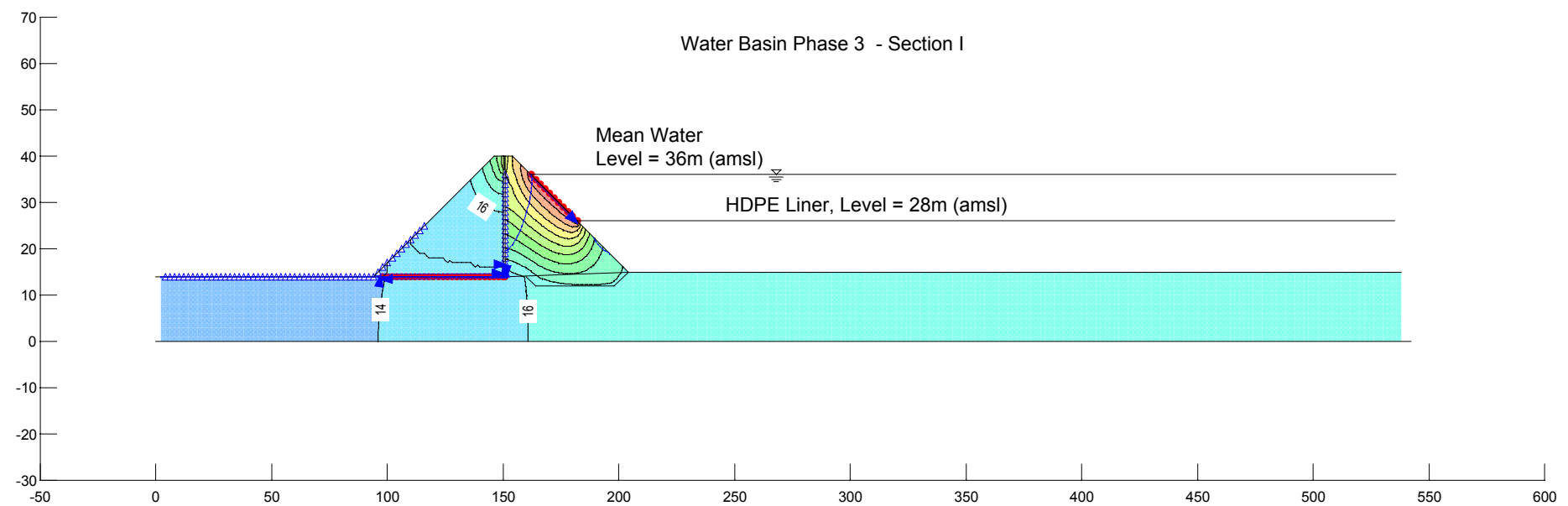


Figure E16: Water Basin – Phase 3.

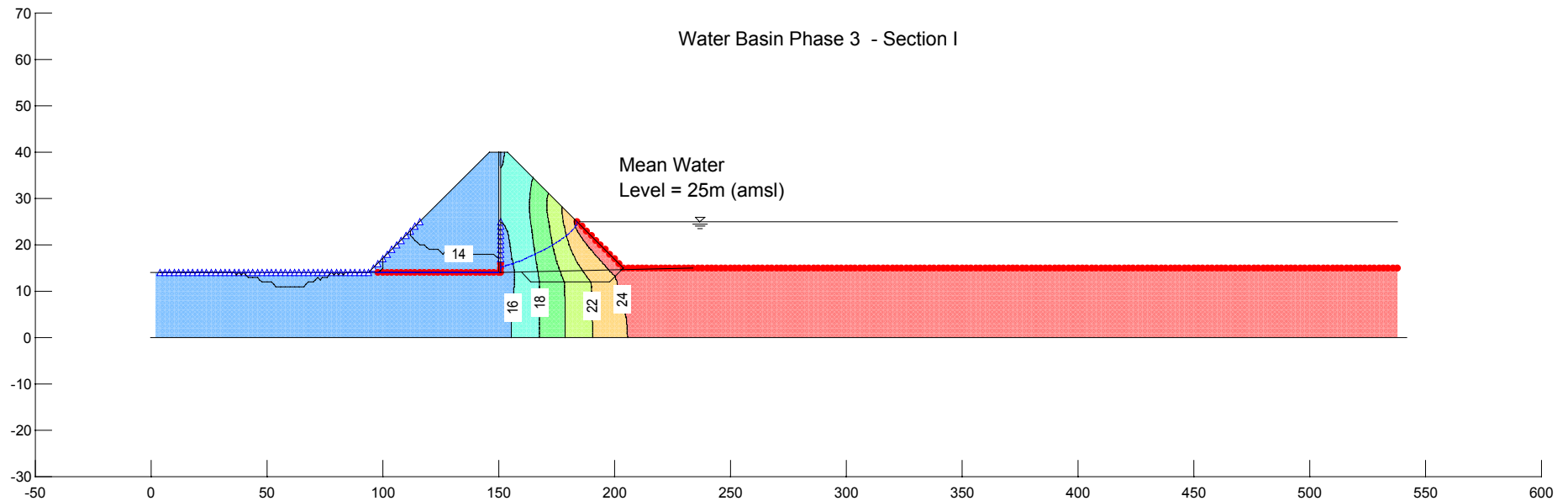


Figure E17: Water Basin – Phase 3.

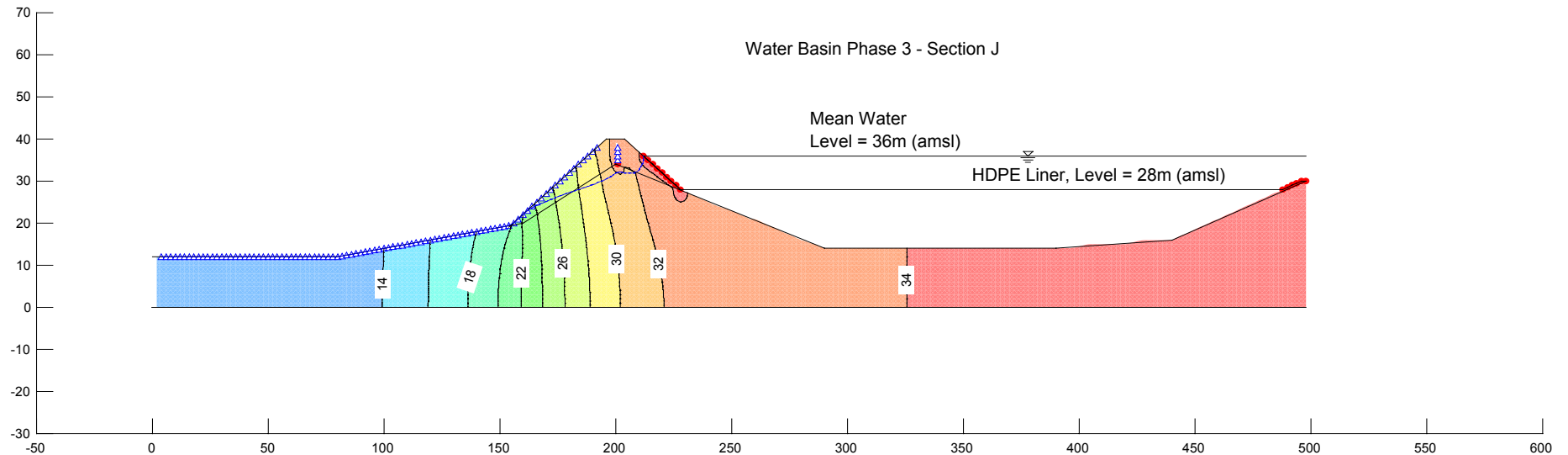


Figure E18: Water Basin – Phase 3.

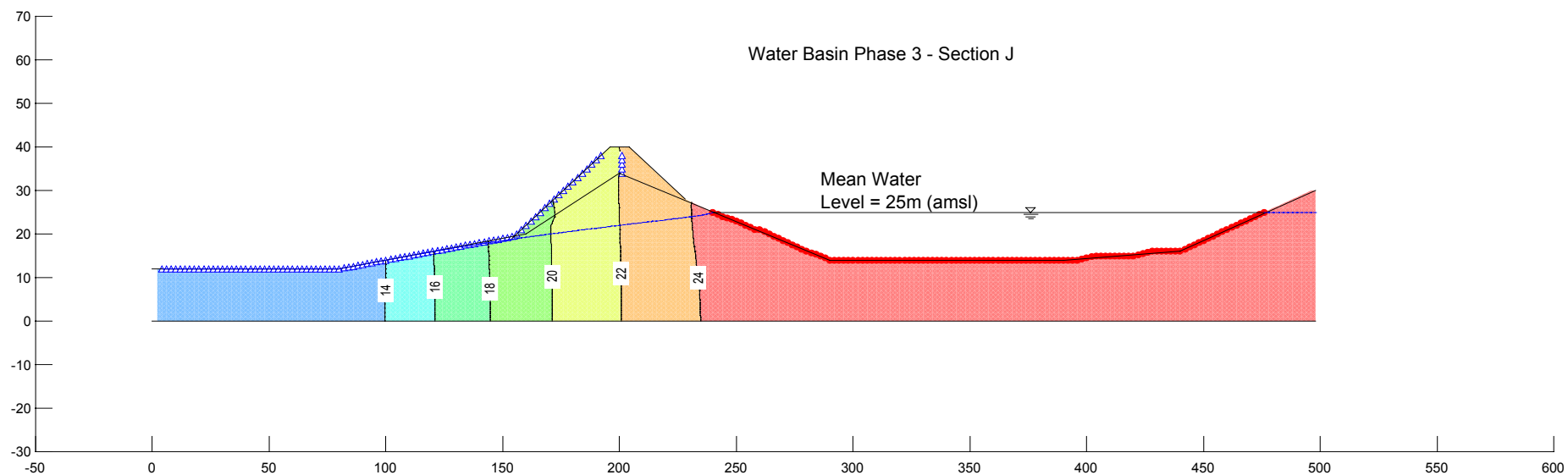


Figure E19: Tailings Basin Closure.

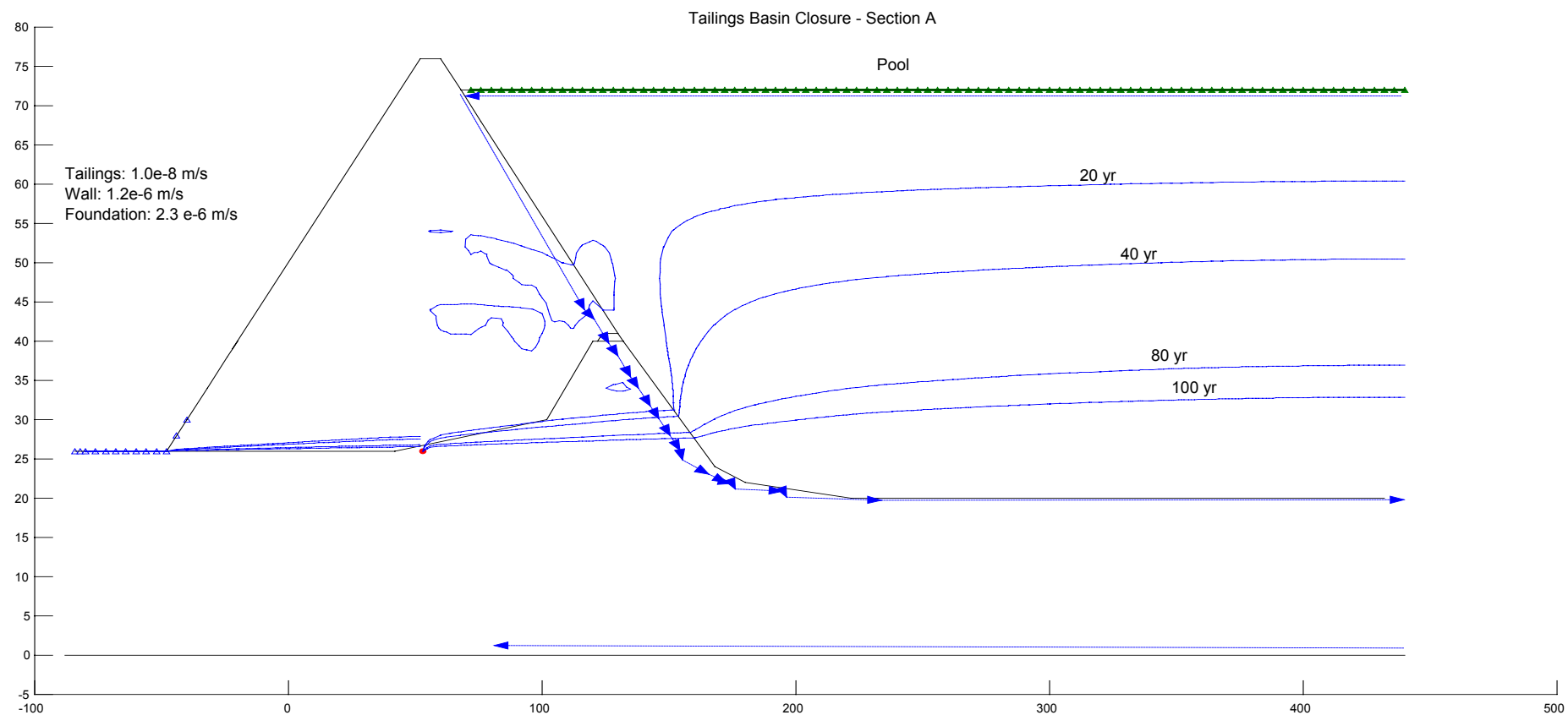


Figure E20: Tailings Basin Closure.

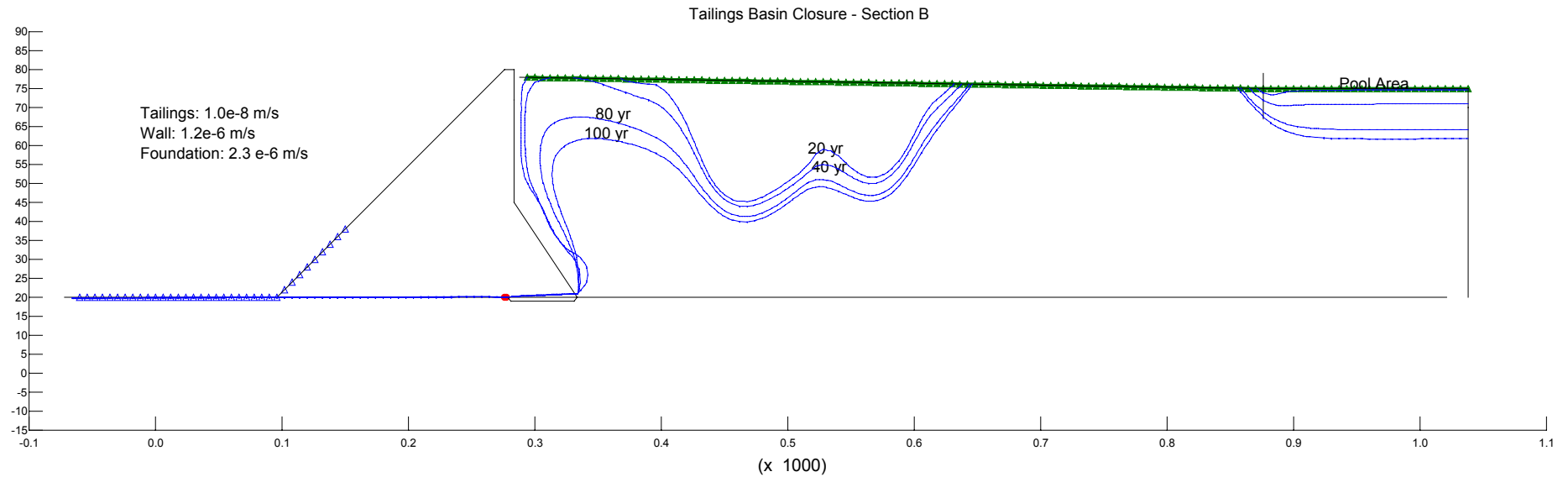


Figure E21: Tailings Basin Closure.

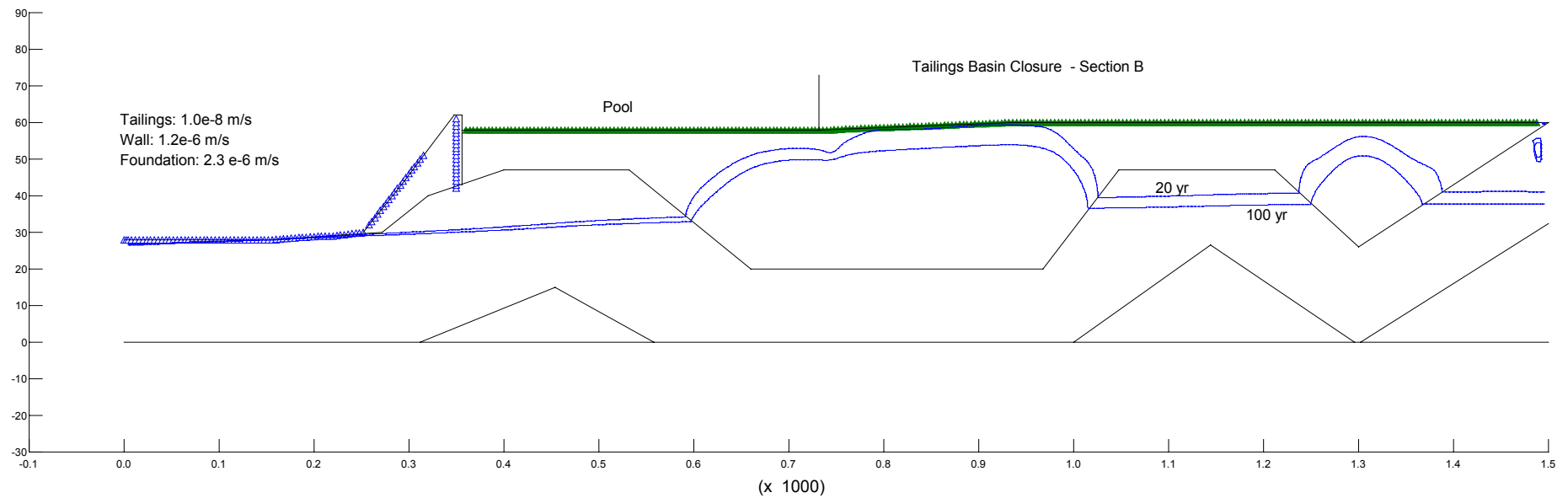


Figure E22: Tailings Basin Closure.

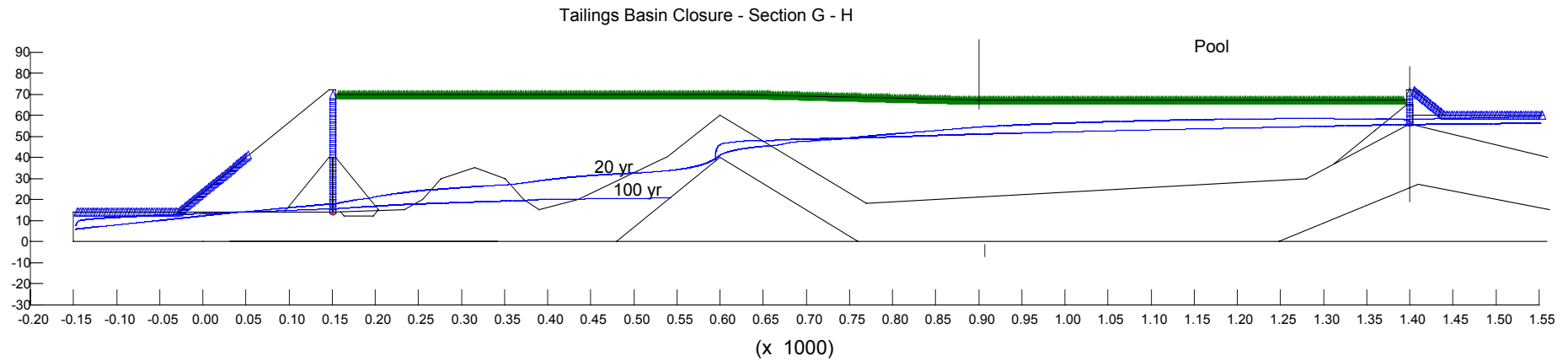
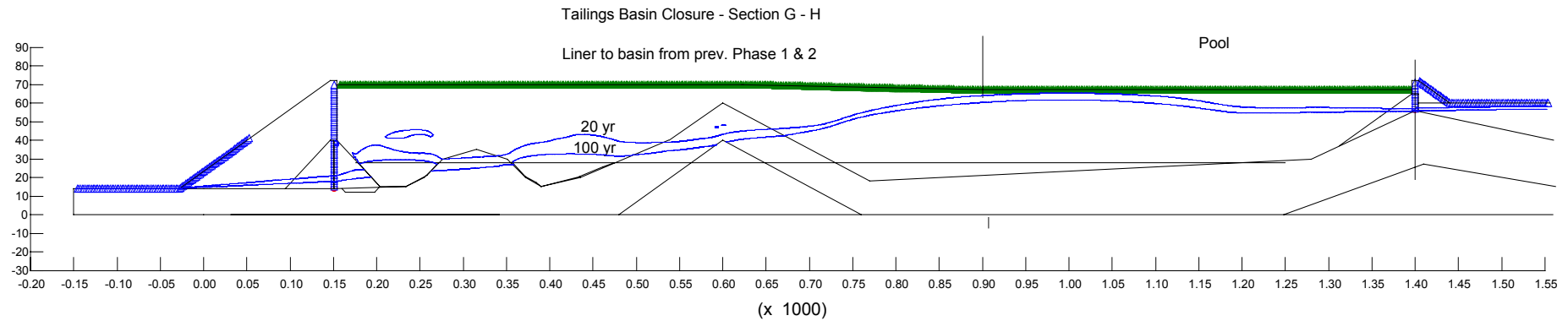


Figure E23: Tailings Basin Closure.



CALCULATIONS

Phase 1 - Year 1

Water Basin - Phase 1 (water level @ 25m)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Mean water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
C	321.1	1.89E-06	5.88072E-09	317950	0.00187	4846	162	0.0005081
D Wall	24.6	2.30E-06	9.34878E-08	317950	0.02972	77046	2568	0.0080773
D	64.8	6.95E-06	1.07211E-07	317950	0.03409	88356	2945	0.0092631
D	102.6	4.58E-09	4.46209E-11	317950	0.00001	37	1	3.855E-06
					Average	42571	1419	0.00446
Estimated seepage to drains							650	
Estimated seepage to groundwater							769	

Water Basin - Phase 1 HDPE Liner up to level 28m (water level @ 36m)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Mean water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
C	21.5	5.06E-06	2.35149E-07	344500	0.08101	209975	6999	0.0203169
D Wall	17.9	4.94E-06	2.75838E-07	344500	0.09503	246308	8210	0.0238324
D	85.4	6.72E-06	7.87248E-08	344500	0.02712	70297	2343	0.0068018
D	40.8	1.50E-08	3.66667E-10	344500	0.00013	327	11	3.168E-05
					Average	131727	4391	0.01275
Estimated seepage to drains							1000	
Estimated seepage to groundwater							3391	

Tailings Basin - Phase 1 (pool @ 43m & tailings @ 41m)

Tailings Dam Basin (pool area)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
A	322.9	1.89E-06	5.86312E-09	842000	0.00494	12796	427	0.0005066
B	162	5.63E-07	3.47654E-09	842000	0.00293	7587	253	0.0003004
E	121.5	5.17E-07	4.2521E-09	842000	0.00358	9280	309	0.0003674
					Average	9888	330	0.00039

Tailings Dam Basin (Beach)								
Section	Flux section length (m)	Basin Flux m ³ /s		Tailings basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
B	540	4.09E-07	7.56926E-10	1085000	0.000821	2129	71	6.54E-05
					Average	2129	71	0.000065

Total seepage from Tailings Dam Phase 1	
Pool area	330 m ³ /day
Beach	71 m ³ /day
Total	401 m³/day
Total water with slurry	1,141,425.4 m ³ /month
Total water with slurry	38,047.5 m ³ /day
Seepage losses as % of slurry water	1.1%

Phase 1

Water Basin - Phase 1 (water level @ 25m)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Mean water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
C	321.1	1.89E-06	5.88072E-09	317950	0.00187	4846	162	0.0005081
D Wall	24.6	2.30E-06	9.34878E-08	317950	0.02972	77046	2568	0.0080773
D	64.8	6.95E-06	1.07211E-07	317950	0.03409	88356	2945	0.0092631
D	102.6	4.58E-09	4.46209E-11	317950	0.00001	37	1	3.855E-06
					Average	42571	1419	0.00446
Estimated seepage to drains							650	
Estimated seepage to groundwater							769	

Water Basin - Phase 1 HDPE Liner up to level 28m (water level @ 36m)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Mean water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
C	21.5	5.06E-06	2.35149E-07	344500	0.08101	209975	6999	0.0203169
D Wall	17.9	4.94E-06	2.75838E-07	344500	0.09503	246308	8210	0.0238324
D	85.4	6.72E-06	7.87248E-08	344500	0.02712	70297	2343	0.0068018
D	40.8	1.50E-08	3.66667E-10	344500	0.00013	327	11	3.168E-05
					Average	131727	4391	0.01275
Estimated seepage to drains							1000	
Estimated seepage to groundwater							3391	

Tailings Basin - Phase 1 (pool @ 76m & tailings @ 78m)

Tailings Dam Basin (pool area)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
A	368.9	2.64E-06	7.15316E-09	460000	0.00329	8529	284	0.000618
B	162	1.45E-07	8.92593E-10	460000	0.00041	1064	35	7.712E-05
E	146.3	8.33E-07	5.69515E-09	460000	0.00262	6790	226	0.0004921
					Average	5461	182	0.00040

Tailings Dam Basin (Beach downstream)								
Section	Flux section length (m)	Basin Flux m ³ /s		Tailings basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
B	540	3.81E-07	7.0587E-10	1.68E+06	0.001182	3065	102	6.099E-05
					Average	3065	102	0.000061

Tailings Dam Basin (Beach upstream)								
Section	Flux section length (m)	Basin Flux m ³ /s		Tailings basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
E	563.2	5.04E-07	8.94105E-10	1702140	0.001522	3945	131	7.725E-05
					Average	3945	131	0.000077

Total seepage from Tailings Dam Phase 1	
Pool area	182 m ³ /day
Beach downstream	102 m ³ /day
Beach upstream	131 m ³ /day
Total	416 m³/day
Total water with slurry	1,141,425.4 m ³ /month
Total water with slurry	38,047.5 m ³ /day
Seepage losses as % of slurry water	1.1%

Phase 2

Water Basin - Phase 1 (water level @ 25m)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Mean water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
C	321.1	1.89E-06	5.88072E-09	317950	0.00187	4846	162	0.0005081
D Wall	24.6	2.30E-06	9.34878E-08	317950	0.02972	77046	2568	0.0080773
D	64.8	6.95E-06	1.07211E-07	317950	0.03409	88356	2945	0.0092631
D	102.6	4.58E-09	4.46209E-11	317950	0.00001	37	1	3.855E-06
					Average	42571	1419	0.00446
Estimated seepage to drains							650	
Estimated seepage to groundwater							769	

Water Basin - Phase 1 HDPE Liner up to level 28m (water level @ 36m)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Mean water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
C	21.5	5.06E-06	2.35149E-07	344500	0.08101	209975	6999	0.0203169
D Wall	17.9	4.94E-06	2.75838E-07	344500	0.09503	246308	8210	0.0238324
D	85.4	6.72E-06	7.87248E-08	344500	0.02712	70297	2343	0.0068018
D	40.8	1.50E-08	3.66667E-10	344500	0.00013	327	11	3.168E-05
					Average	131727	4391	0.01275
Estimated seepage to drains							1000	
Estimated seepage to groundwater							3391	

Tailings Basin - Phase 2 (pool @ 60m & tailings @62m)

Tailings Dam Basin (pool area)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
F	272.2	4.26E-07	1.5633E-09	220000	0.00034	891	30	0.0001351
					Average	891	30	0.00014

Tailings Dam Basin (Beach)								
Section	Flux section length (m)	Basin Flux m ³ /s		Tailings basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
F	753.8	6.85E-07	9.08623E-10	2.15E+06	0.001956	5069	168.97	7.851E-05
					Average	5069	168.97	0.0000785

Total seepage from Tailings Dam Phase 2	
Pool area	30 m ³ /day
Beach	168.97 m ³ /day
Total	198.68 m³/day
Total water with slurry	1,141,425.4 m ³ /month
Total water with slurry	38,047.5 m ³ /day
Seepage losses as % of slurry water	0.522%

Phase 3

Water Basin - Phase 3 (water level @ 25m)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Mean water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
I	334	5.14E-06	1.53766E-08	262800	0.00404	10474	349	0.0013285
I Wall	22.4	2.30E-06	1.0267E-07	262800	0.02698	69936	2331	0.0088707
J	238.3	5.61E-06	2.35271E-08	262800	0.00618	16026	534	0.0020327
					Average	32146	1072	0.00408
Estimated seepage to drains							220	
Estimated seepage to groundwater							852	

Water Basin - Phase 3 HDPE Liner up to level 28m (water level @ 36m)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Mean water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
I	17.9	7.82E-06	4.36709E-07	136000	0.05939	153945	5132	0.0377317
J	17.9	7.16E-06	4.00218E-07	136000	0.05443	141082	4703	0.0345788
J	12.8	5.54E-07	4.32758E-08	136000	0.00589	15255	509	0.003739
					Average	103427	3448	0.02535
Estimated seepage to drains							120	
Estimated seepage to groundwater							3328	

Tailings Basin - Phase 3 (pool @ 68m & tailings @ 70m) No liner to basin

Tailings Dam Basin (pool area)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
G-H	497	4.33E-06	8.72052E-09	200000	0.00174	4521	151	0.0007535
					Average	4521	151	0.00075

Tailings Dam Basin (Beach)								
Section	Flux section length (m)	Basin Flux m ³ /s		Tailings basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
G-H	770.5	3.90E-07	5.05983E-10	1.51E+06	0.000766	1985	66.17	4.372E-05
					Average	1985	66.17	0.0000437

Total seepage from Tailings Dam Phase 3	
Pool area	151 m ³ /day
Beach	66.17 m ³ /day
Total	216.86 m³/day
Total water with slurry	1,141,425.4 m ³ /month
Total water with slurry	38,047.5 m ³ /day
Seepage losses as % of slurry water	0.570%

Phase 3

Water Basin - Phase 3 (water level @ 25m)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Mean water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
I	334	5.14E-06	1.53766E-08	262800	0.00404	10474	349	0.0013285
I Wall	22.4	2.30E-06	1.0267E-07	262800	0.02698	69936	2331	0.0088707
J	238.3	5.61E-06	2.35271E-08	262800	0.00618	16026	534	0.0020327
					Average	32146	1072	0.00408
Estimated seepage to drains							220	
Estimated seepage to groundwater							852	

Water Basin - Phase 3 HDPE Liner up to level 28m (water level @ 36m)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Mean water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
I	17.9	7.82E-06	4.36709E-07	136000	0.05939	153945	5132	0.0377317
J	17.9	7.16E-06	4.00218E-07	136000	0.05443	141082	4703	0.0345788
J	12.8	5.54E-07	4.32758E-08	136000	0.00589	15255	509	0.003739
					Average	103427	3448	0.02535
Estimated seepage to drains							120	
Estimated seepage to groundwater							3328	

Tailings Basin - Phase 3 (pool @ 68m & tailings @ 70m)

Liner to basin

Tailings Dam Basin (pool area)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
G-H	497	2.88E-06	5.7994E-09	200000	0.00116	3006	100	0.0005011
					Average	3006	100	0.00050

Tailings Dam Basin (Beach)								
Section	Flux section length (m)	Basin Flux m ³ /s		Tailings basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
G-H	770.5	3.51E-07	4.55328E-10	1.51E+06	0.000689	1786	59.55	3.934E-05
					Average	1786	59.55	0.0000393

Total seepage from Tailings Dam Phase 3	
Pool area	100 m ³ /day
Beach	59.55 m ³ /day
Total	159.76 m³/day
Total water with slurry	1,141,425.4 m ³ /month
Total water with slurry	38,047.5 m ³ /day
Seepage losses as % of slurry water	0.420%

Phase 1 - Post Closure
Tailings Basin 20 year after closure

Tailings Dam Basin (pool area)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
A	368.9	2.47E-06	6.68772E-09	80000	0.00054	1387	46	0.0005778
B	162	1.43E-07	8.81543E-10	80000	0.00007	183	6	7.617E-05
E	146.3	3.54E-07	2.42023E-09	80000	0.00019	502	17	0.0002091
Average						690	23	0.00029

Tailings Dam Basin (Beach downstream)								
Section	Flux section length (m)	Basin Flux m ³ /s		Tailings basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
B	540	4.04E-07	7.475E-10	2.05E+06	0.001533	3974	132	6.458E-05
Average						3974	132	0.000065

Tailings Dam Basin (Beach upstream)								
Section	Flux section length (m)	Basin Flux m ³ /s		Tailings basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
E	563.2	3.36E-06	5.9739E-09	1702140	0.010168	26357	879	0.0005161
Average						26357	879	0.000516

Total seepage from Tailings Dam Phase 1 - 20 year	
Pool area	23 m ³ /day
Beach downstream	132 m ³ /day
Beach upstream	879 m ³ /day
Total	1034 m³/day
Total water with slurry	1,141,425.4 m ³ /month
Total water with slurry	38,047.5 m ³ /day
Seepage losses as % of slurry water	2.7%

Phase 1 - Post Closure
Tailings Basin 60 year after closure

Tailings Dam Basin (pool area)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
A	368.9	1.36E-06	3.68718E-09	80000	0.00029	765	25	0.0003186
B	162	1.42E-07	8.76049E-10	80000	0.00007	182	6	7.569E-05
E	146.3	1.73E-07	1.18483E-09	80000	0.00009	246	8	0.0001024
Average						397	13	0.00017

Tailings Dam Basin (Beach downstream)								
Section	Flux section length (m)	Basin Flux m ³ /s		Tailings basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
B	540	4.05E-07	7.49407E-10	2.05E+06	0.001537	3984	133	6.475E-05
Average						3984	133	0.000065

Tailings Dam Basin (Beach upstream)								
Section	Flux section length (m)	Basin Flux m ³ /s		Tailings basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
E	563.2	6.91E-07	1.2274E-09	1702140	0.002089	5415	181	0.000106
Average						5415	181	0.000106

Total seepage from Tailings Dam Phase 1 - 60 year	
Pool area	13 m ³ /day
Beach downstream	133 m ³ /day
Beach upstream	181 m ³ /day
Total	327 m³/day
Total water with slurry	1,141,425.4 m ³ /month
Total water with slurry	38,047.5 m ³ /day
Seepage losses as % of slurry water	0.9%

Phase 1 - Post Closure
Tailings Basin 100 year after closure

Tailings Dam Basin (pool area)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
A	368.9	6.78E-07	1.83692E-09	8000	0.00001	38	1	0.0001587
B	162	1.42E-07	8.76049E-10	8000	0.00001	18	1	7.569E-05
E	146.3	1.24E-07	8.47505E-10	8000	0.00001	18	1	7.322E-05
Average						25	1	0.00010

Tailings Dam Basin (Beach downstream)								
Section	Flux section length (m)	Basin Flux m ³ /s		Tailings basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
B	540	3.93E-07	7.28426E-10	2.05E+06	0.001494	3872	129	6.294E-05
Average						3872	129	0.000063

Tailings Dam Basin (Beach upstream)								
Section	Flux section length (m)	Basin Flux m ³ /s		Tailings basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
E	563.2	2.90E-07	5.14311E-10	1702140	0.000875	2269	76	4.444E-05
Average						2269	76	0.000044

Total seepage from Tailings Dam Phase 1 - 100 year	
Pool area	1 m ³ /day
Beach downstream	129 m ³ /day
Beach upstream	76 m ³ /day
Total	206 m³/day
Total water with slurry	1,141,425.4 m ³ /month
Total water with slurry	38,047.5 m ³ /day
Seepage losses as % of slurry water	0.5%

Phase 2 - Post Closure
Tailings Basin 20 year after closure

Tailings Dam Basin (pool area)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
F	272.2	2.12E-07	7.78986E-10	80000	0.00006	162	5	6.73E-05
Average					162	5	0.00007	

Tailings Dam Basin (Beach)								
Section	Flux section length (m)	Basin Flux m ³ /s		Tailings basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
F	753.8	5.51E-07	7.30698E-10	2.29E+06	0.001674	4339	144.64	6.313E-05
Average					4339	144.64	0.0000631	

Total seepage from Tailings Dam Phase 2 - 20 year	
Pool area	5 m ³ /day
Beach	144.64 m ³ /day
Total	150.02 m³/day
Total water with slurry	1,141,425.4 m ³ /month
Total water with slurry	38,047.5 m ³ /day
Seepage losses as % of slurry water	0.394%

Phase 2 - Post Closure
Tailings Basin 60 year after closure

Tailings Dam Basin (pool area)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
F	272.2	2.10E-07	7.70096E-10	80000	0.00006	160	5	6.654E-05
Average						160	5	0.00007

Tailings Dam Basin (Beach)								
Section	Flux section length (m)	Basin Flux m ³ /s		Tailings basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
F	753.8	4.55E-07	6.03489E-10	2.29E+06	0.001383	3584	119.46	5.214E-05
Average						3584	119.46	0.0000521

Total seepage from Tailings Dam Phase 2 - 60 year	
Pool area	5 m ³ /day
Beach	119.46 m ³ /day
Total	124.78 m³/day
Total water with slurry	1,141,425.4 m ³ /month
Total water with slurry	38,047.5 m ³ /day
Seepage losses as % of slurry water	0.328%

Phase 2 - Post Closure
Tailings Basin 100 year after closure

Tailings Dam Basin (pool area)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
F	272.2	2.05E-07	7.54519E-10	80000	0.00006	156	5	6.519E-05
					Average	156	5	0.00007

Tailings Dam Basin (Beach)								
Section	Flux section length (m)	Basin Flux m ³ /s		Tailings basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
F	753.8	4.62E-07	6.12842E-10	2.29E+06	0.001404	3639	121.31	5.295E-05
					Average	3639	121.31	0.0000529

Total seepage from Tailings Dam Phase 2 - 100 year	
Pool area	5 m ³ /day
Beach	121.31 m ³ /day
Total	126.52 m³/day
Total water with slurry	1,141,425.4 m ³ /month
Total water with slurry	38,047.5 m ³ /day
Seepage losses as % of slurry water	0.333%

Phase 3 - Post Closure
Tailings Basin 20 year after closure - no liner

Tailings Dam Basin (pool area)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
G-H	497	8.79E-07	1.76948E-09	80000	0.00014	367	12	0.0001529
Average						367	12	0.00015

Tailings Dam Basin (Beach)								
Section	Flux section length (m)	Basin Flux m ³ /s		Tailings basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
G-H	770.5	3.60E-07	4.67502E-10	1.64E+06	0.000764	1981	66.04	4.039E-05
Average						1981	66.04	0.0000404

Total seepage from Tailings Dam Phase 3 - 20 yeas	
Pool area	12 m ³ /day
Beach	66.04 m ³ /day
Total	78.27 m³/day
Total water with slurry	1,141,425.4 m ³ /month
Total water with slurry	38,047.5 m ³ /day
Seepage losses as % of slurry water	0.206%

Phase 3 - Post Closure
Tailings Basin 60 year after closure - no liner

Tailings Dam Basin (pool area)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
G-H	497	1.02E-06	2.04507E-09	80000	0.00016	424	14	0.0001767
Average						424	14	0.00018

Tailings Dam Basin (Beach)								
Section	Flux section length (m)	Basin Flux m ³ /s		Tailings basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
G-H	770.5	6.63E-07	8.59974E-10	1.64E+06	0.001406	3645	121.48	7.43E-05
Average						3645	121.48	0.0000743

Total seepage from Tailings Dam Phase 3 - 60 yeas	
Pool area	14 m ³ /day
Beach	121.48 m ³ /day
Total	135.62 m³/day
Total water with slurry	1,141,425.4 m ³ /month
Total water with slurry	38,047.5 m ³ /day
Seepage losses as % of slurry water	0.356%

Phase 3 - Post Closure
Tailings Basin 100 year after closure - no liner

Tailings Dam Basin (pool area)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
G-H	497	4.34E-08	8.7328E-11	80000	0.00001	18	1	7.545E-06
Average						18	1	0.00001

Tailings Dam Basin (Beach)								
Section	Flux section length (m)	Basin Flux m ³ /s		Tailings basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
G-H	770.5	2.92E-07	3.79455E-10	1.64E+06	0.000620	1608	53.60	3.278E-05
Average						1608	53.60	0.0000328

Total seepage from Tailings Dam Phase 3 - 100 yeas	
Pool area	1 m ³ /day
Beach	53.60 m ³ /day
Total	54.21 m³/day
Total water with slurry	1,141,425.4 m ³ /month
Total water with slurry	38,047.5 m ³ /day
Seepage losses as % of slurry water	0.142%

Phase 3 - Post Closure
Tailings Basin 20 year after closure - liner to basin

Tailings Dam Basin (pool area)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
G-H	497	5.61E-07	1.12911E-09	80000	0.00009	234	8	9.756E-05
					Average	234	8	0.00010

Tailings Dam Basin (Beach)								
Section	Flux section length (m)	Basin Flux m ³ /s		Tailings basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
G-H	770.5	1.31E-06	1.70292E-09	1.64E+06	0.002784	7217	240.56	0.0001471
					Average	7217	240.56	0.0001471

Total seepage from Tailings Dam Phase 3 - 20 year	
Pool area	8 m ³ /day
Beach	240.56 m ³ /day
Total	248.37 m³/day
Total water with slurry	1,141,425.4 m ³ /month
Total water with slurry	38,047.5 m ³ /day
Seepage losses as % of slurry water	0.653%

Phase 3 - Post Closure
Tailings Basin 60 year after closure - liner to basin

Tailings Dam Basin (pool area)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
G-H	497	6.39E-07	1.28563E-09	80000	0.00010	267	9	0.0001111
					Average	267	9	0.00011

Tailings Dam Basin (Beach)								
Section	Flux section length (m)	Basin Flux m ³ /s		Tailings basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
G-H	770.5	1.46E-07	1.88838E-10	1.64E+06	0.000309	800	26.68	1.632E-05
					Average	800	26.68	0.0000163

Total seepage from Tailings Dam Phase 3 - 60 year	
Pool area	9 m ³ /day
Beach	26.68 m ³ /day
Total	35.56 m³/day
Total water with slurry	1,141,425.4 m ³ /month
Total water with slurry	38,047.5 m ³ /day
Seepage losses as % of slurry water	0.093%

Phase 3 - Post Closure
Tailings Basin 100 year after closure - liner to basin

Tailings Dam Basin (pool area)								
Section	Flux section length (m)	Basin Flux m ³ /s	Basin Flux m ³ /s/m	Water basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
G-H	497	5.06E-07	1.01845E-09	200000	0.00020	528	18	8.799E-05
Average						528	18	0.00009

Tailings Dam Basin (Beach)								
Section	Flux section length (m)	Basin Flux m ³ /s		Tailings basin area m ²	Basin Seepage m ³ /s	Basin Seepage m ³ /month	Basin Seepage m ³ /day	Basin Seepage m ³ /day/m ²
G-H	770.5	7.03E-07	9.12161E-10	1.51E+06	0.001381	3579	119.29	7.881E-05
Average						3579	119.29	0.0000788

Total seepage from Tailings Dam Phase 3 - 100 year	
Pool area	18 m ³ /day
Beach	119.29 m ³ /day
Total	136.89 m³/day
Total water with slurry	1,141,425.4 m ³ /month
Total water with slurry	38,047.5 m ³ /day
Seepage losses as % of slurry water	0.360%

APPENDIX F: ACID-BASE TESTING

Acid Base Accounting Tests



Lakefield Research

Report No. CA10090-JUL04

301-116/2

ABA

Title Final Report

Sample ID		*Approved Date	*Approved Time	Soil SA #1
Sample Date/Time				07-Jul-04 08:30
Analysis	Units			
Paste pH	units	06-Aug-04	11:10	7.45
Fizz Rate	---	06-Aug-04	11:10	2
Sample	weight(g)	06-Aug-04	11:10	2.03
HCl added	mL	06-Aug-04	11:10	28.20
HCl	Normality	06-Aug-04	11:10	0.10
NaOH	Normality	06-Aug-04	11:10	0.10
NaOH to	pH=8.3 mL	06-Aug-04	11:10	24.30
Final pH	units	06-Aug-04	11:10	1.71
NP	t CaCO ₃ /1000t	06-Aug-04	11:10	9.6
AP	t CaCO ₃ /1000 t	06-Aug-04	11:10	2.5
Net NP	t CaCO ₃ /1000 t	06-Aug-04	11:10	7.1
NP/AP	ratio	06-Aug-04	11:10	3.8
S	%	04-Aug-04	16:49	7.19
S=	%	04-Aug-04	21:59	0.08
SO ₄	%	04-Aug-04	21:59	21.3
C(t)	%	04-Aug-04	16:49	0.09
CO ₃	%	04-Aug-04	21:58	< 0.05

Guidelines for screening criteria based on NP:AP ratio

NP:AP ratio	Comment
<1:1	Likely AMD generating
1:1 - 2:1	Possibly AMD generating if NP is insufficiently reactive or is depleted at a faster rate than sulphides
2:1 - 4:1	Not potentially AMD generating unless significant preferential exposure of planes, or extremely reactive sulphides in sulphides along fracture planes, or extremely reactive sulphides in combination with insufficiently reactive NP
>4:1	No further AMD testing required unless materials are to be used as a source of alkalinity

APPENDIX G: GROUNDWATER MODELLING

Introduction

A numerical groundwater flow model was constructed with pre- and post-processing package software, in order to simulate the potential impact of the Option 4 Tailings Dam, west of Toamasina, on the groundwater zone. Seepage volumes from the tailings dam, towards the groundwater zone, were modelled with a variable saturation model package. Simulated seepage volumes and qualities, plus field data (Section 3.2.1) were incorporated into the flow and contaminant transport model.

Modelling software

PMWIN, developed by Chaing and Kinzelbach (1999), was used to create the model and to analyse and display the modelling results. It is an internationally accepted modelling package, which uses MODFLOW to calculate the solution of the groundwater flow equation using the finite difference methodology. It simulates steady and non-steady flow in an irregularly shaped flow system in which aquifer layers can be confined, unconfined, or a combination of confined and unconfined. Flow from external stresses, such as flow to boreholes, aerial recharge, evapotranspiration, flow to drains, and flow through riverbeds, can be simulated. MT3D was used for contaminant transport simulations, taking advection, dispersion and sources/sinks into account.

Model construction

Aquifer parameters were mainly obtained from existing data (Section 3.1). A one-layered flow model was constructed due to the lack of site-specific 3D data. Figure G1 shows the model grid used in simulations.

Natural groundwater boundaries were used as model boundaries. The northern, western and southern boundaries were modelled using no-flow cells, simulating groundwater divides. The eastern boundary was taken at the Ambolona Tributary 1 and was modelled using constant head cells. Streams were modelled using the river cell boundaries.

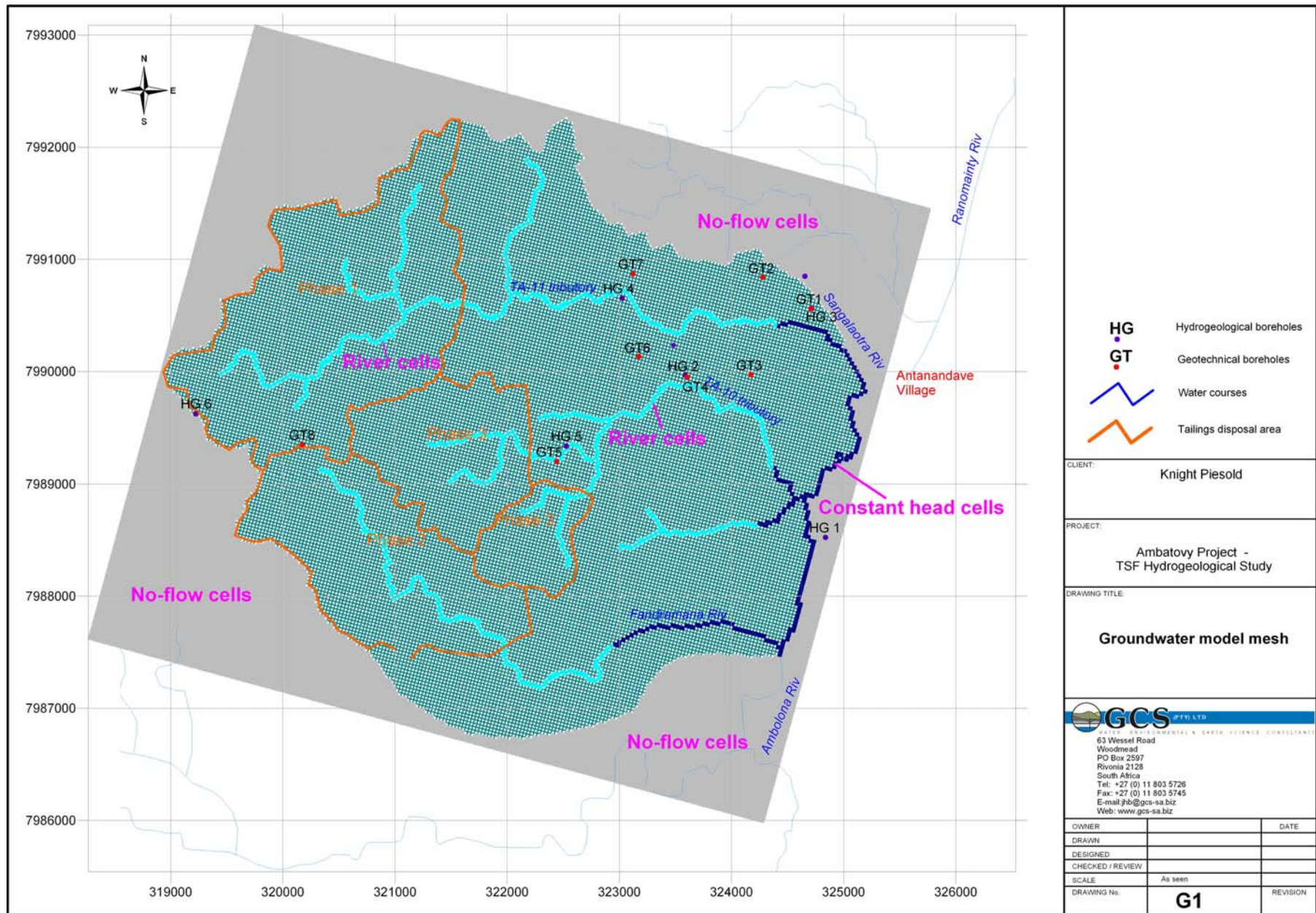
The model layer thickness was estimated to be 20 metres, using field data. The model grid size is 30m x 30m.

Model parameters and calibration

Aquifer parameters used in the model were calibrated, using measured groundwater levels. The model was first calibrated using “natural” steady state conditions in order to simulate pre-tailings dam water levels. The calibration process was done by changing the model parameters for transmissivity, river conductance and recharge. Figure G2 indicates the comparison between modelled heads obtained after calibration and observed heads. A variance of 1.4 was obtained.

Parameters used:

- A transmissivity value of between 3 -7 m²/day, gave best modelling results for the aquifers in the area. These are similar to the aquifer test data.
- Storage values used are 0.1 to 0.3 for the weathered aquifer
- Recharge values of between 70 and 200 mm per annum were used.



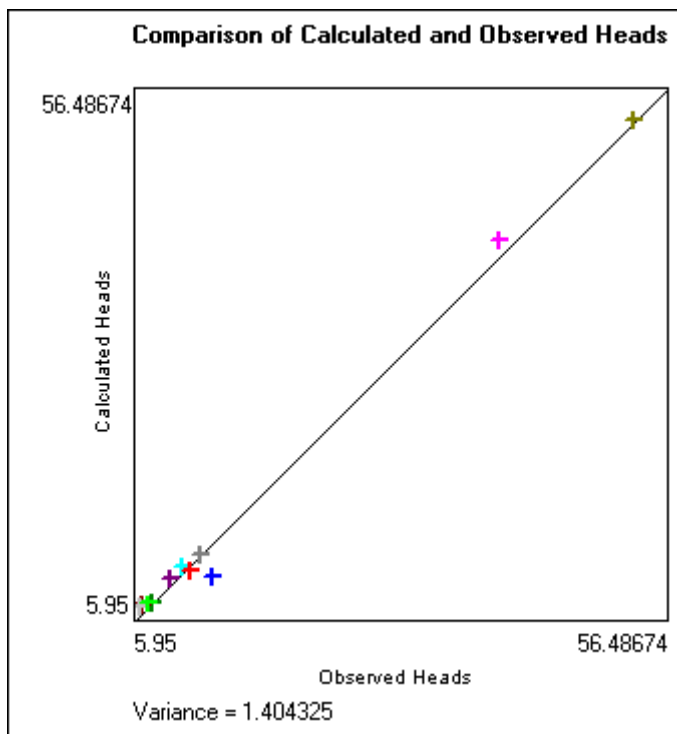


Figure G2: Observed water levels versus modelled water levels.

- River cells were used to simulate stream leakage. River conductance values were based on cell size and the hydraulic conductance (± 0.1 m/day). A river conductance of $9 \text{ m}^2/\text{day}$ was specified.

Sensitivity analysis

A crude sensitivity analysis has been carried out on the calibrated model, to ascertain the influence of parameters on the model results. This process indicates which parameters the model is most sensitive to and thus which parameters need to be determined with the highest possible accuracy. A sensitivity analysis is done by varying one input parameter, keeping all others constant and then observing the resulting changes.

The results of the sensitivity analysis indicate that the water levels in the model are sensitive to changes in transmissivity and recharge and to a lesser extent to river conductance.

Simulating seepage from tailings dam and water basin

Seepage from the tailings dam and water basin was simulated as a flux, using the recharge package.

Contaminated transport model

The calibrated groundwater flow model was used as a basis for developing a contaminant transport model. The MT3DMS package was used in the calculation of salt plumes. The various transport and related aquifer parameters are listed in Table G1. Contaminant movement will mostly take place as a result of advection.

Table G1

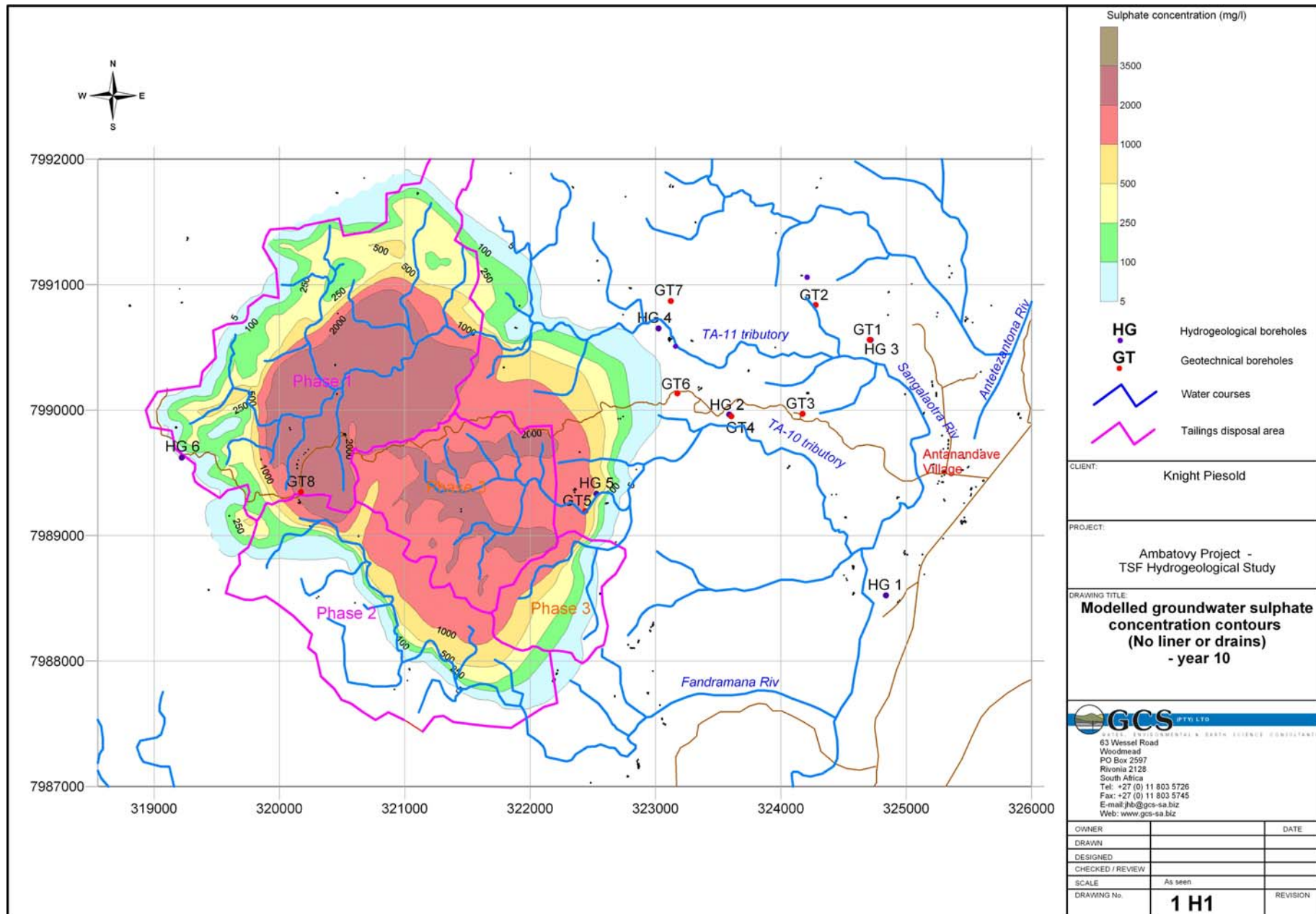
Aquifer thickness (m)	Porosity (%)	Kd (ml/g) for Mn	Molecular Diffusion (m²/s)	Longitudinal Dispersivity (m)	Transverse Dispersivity (m)
±20	Average 1 - 5%	10	0	10	1– tenth of longitudinal dispersivity

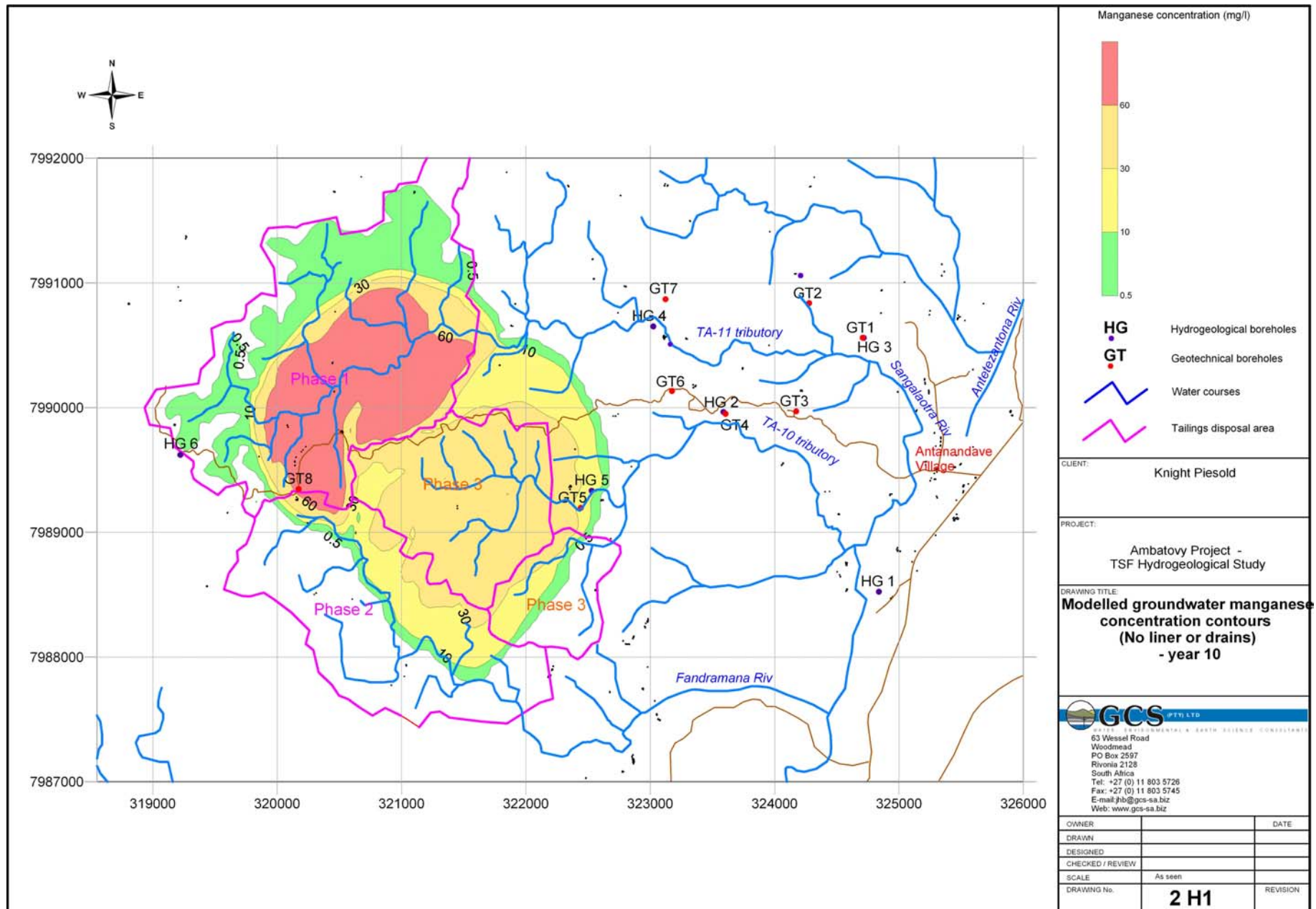
Due to the assumptions made, the results from the contaminant transport model are considered to represent a first approximation of the impact on groundwater quality.

It is advisable to recalibrate the flow model and transport model once more information regarding groundwater levels and water quality become available.

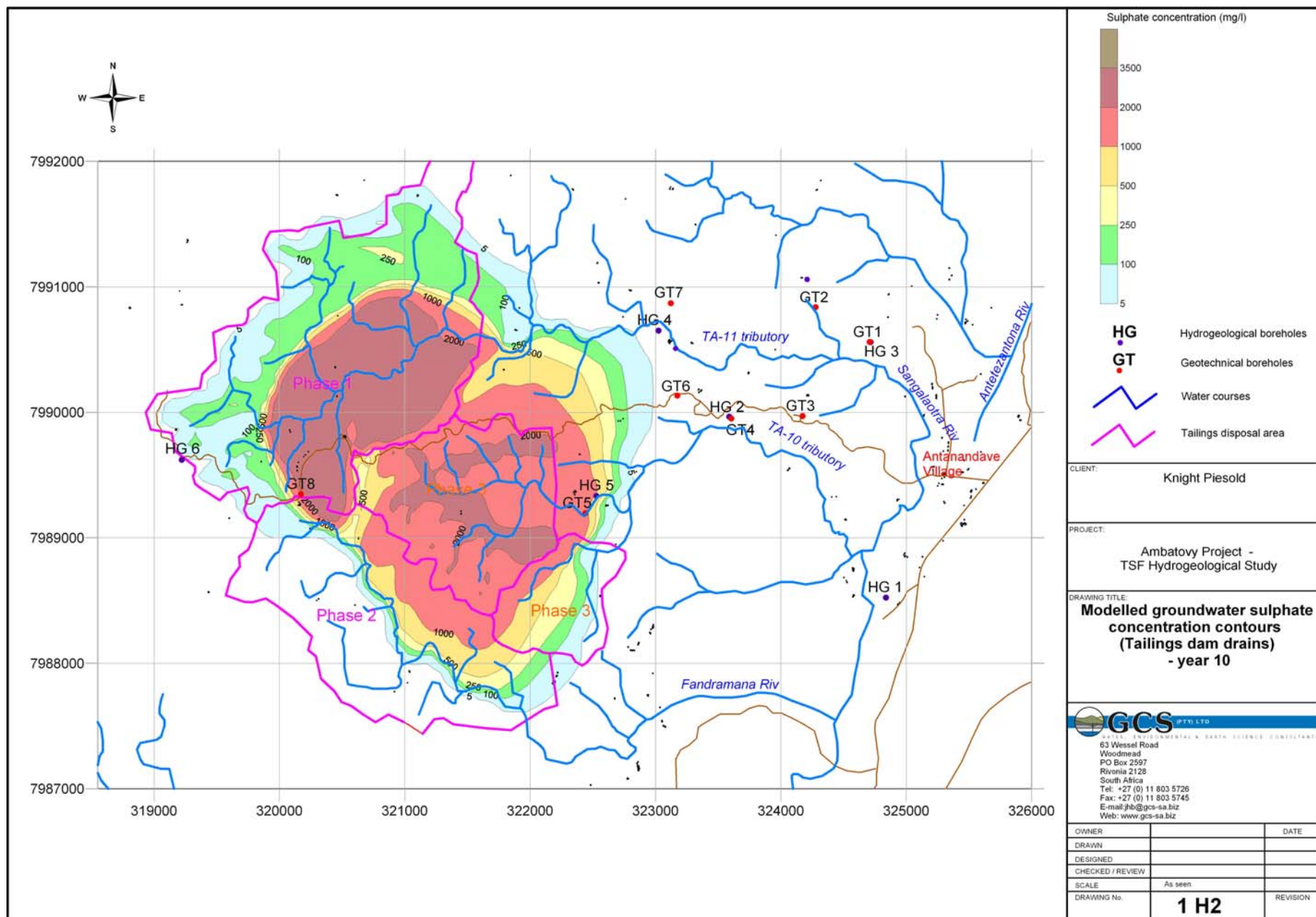
APPENDIX H SIMULATED GROUNDWATER PLUMES

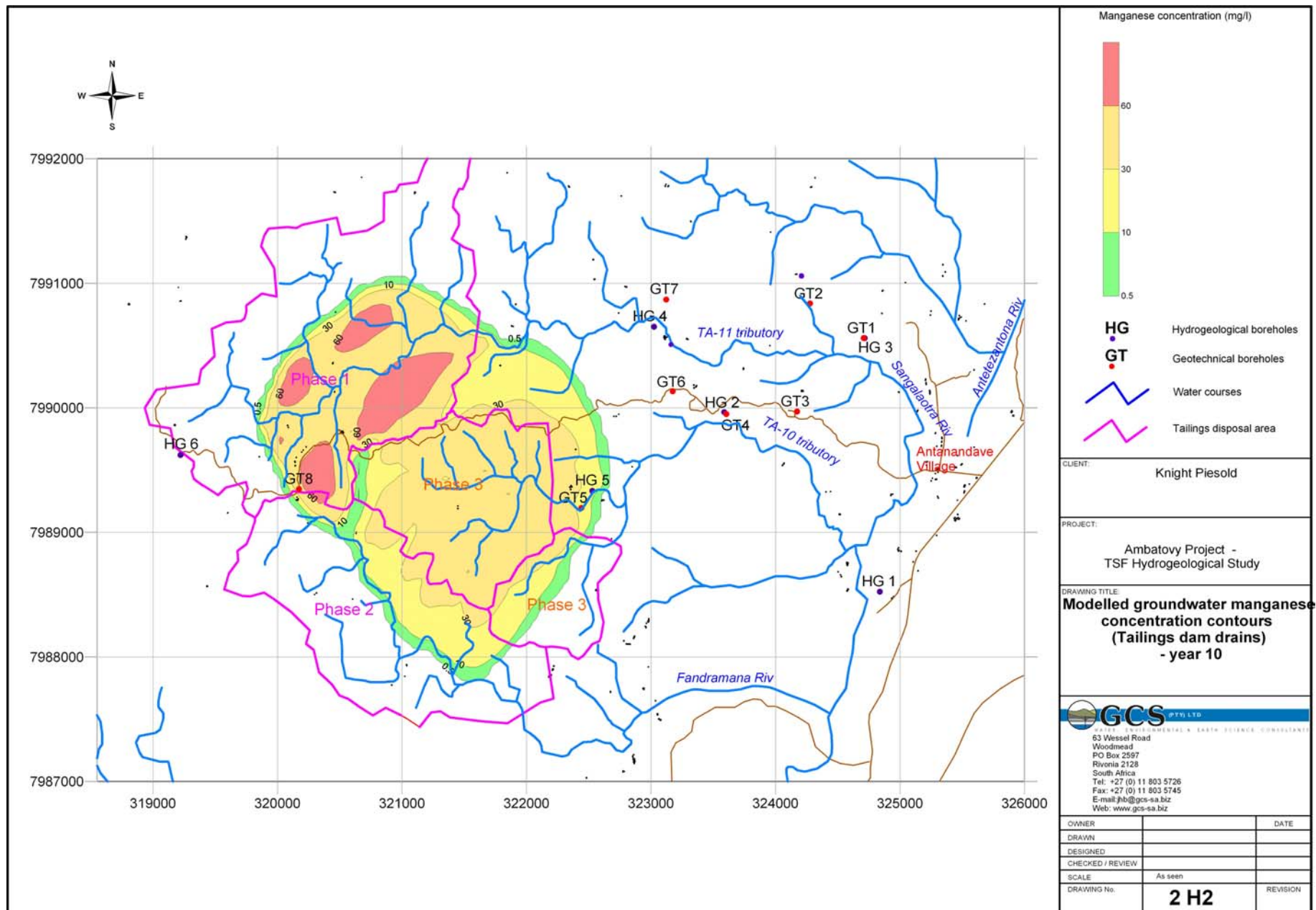
H1 - *Scenario 1* No liner or drains



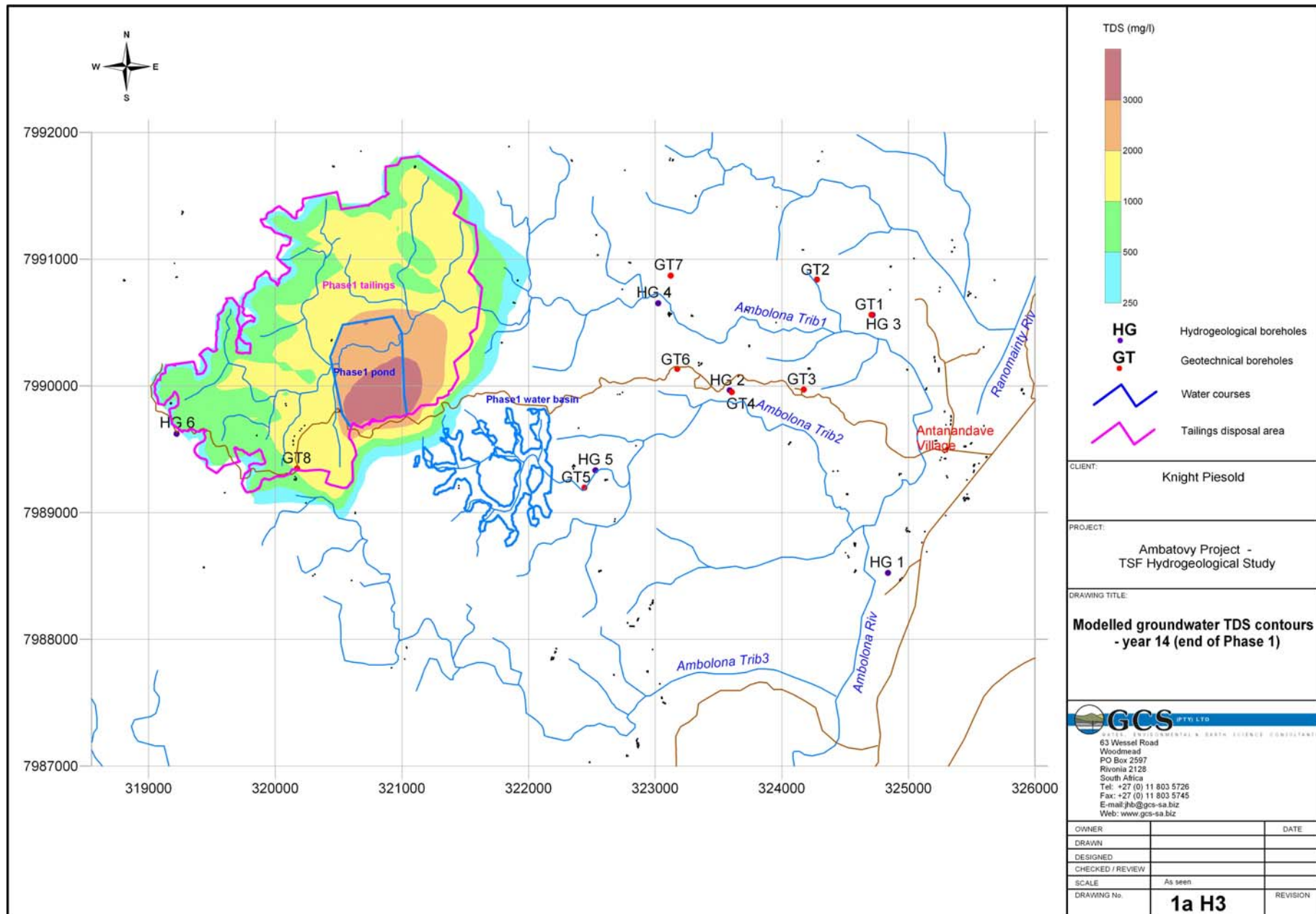


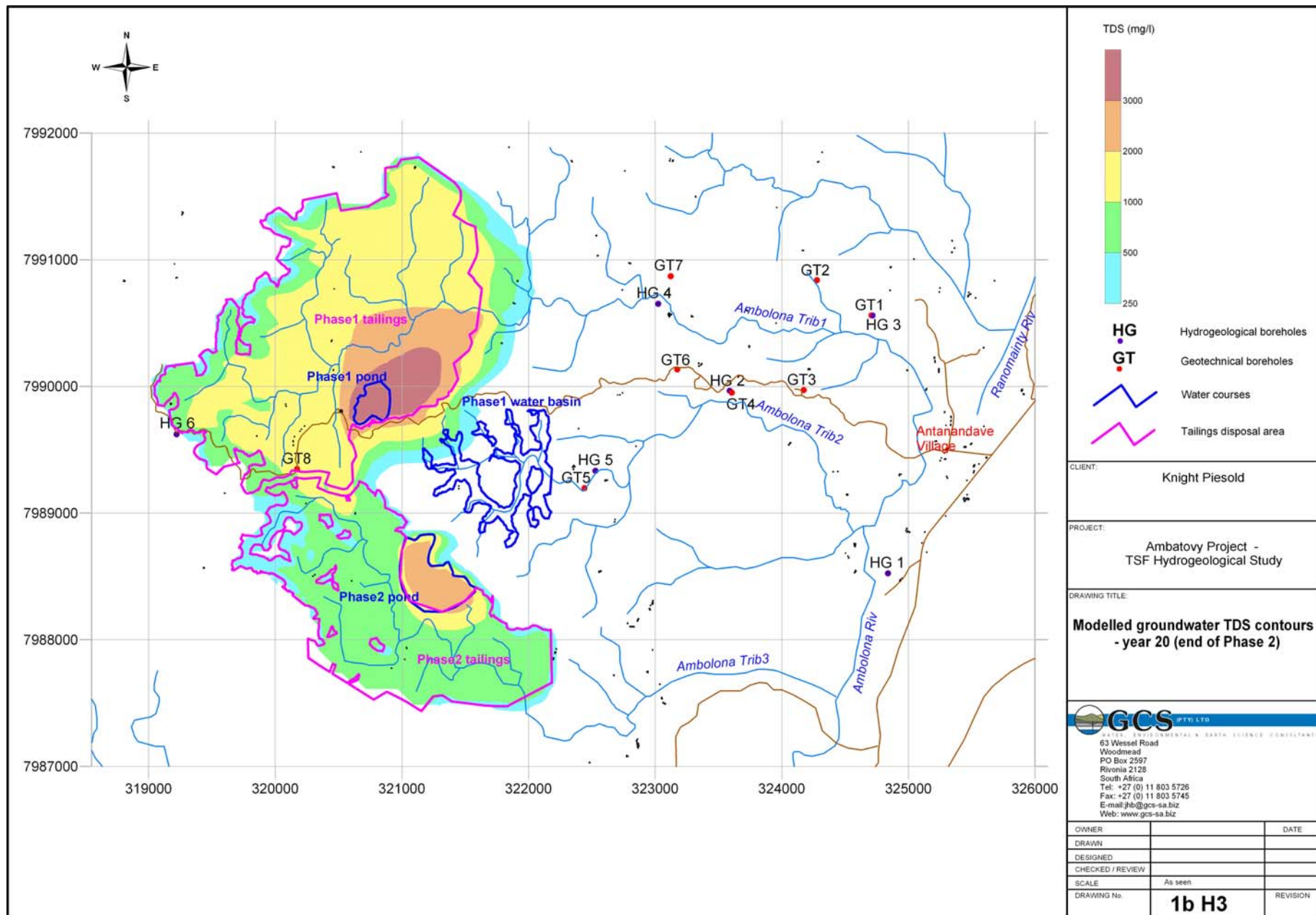
H2 - Scenario 2 Drains below the tailings dam pool

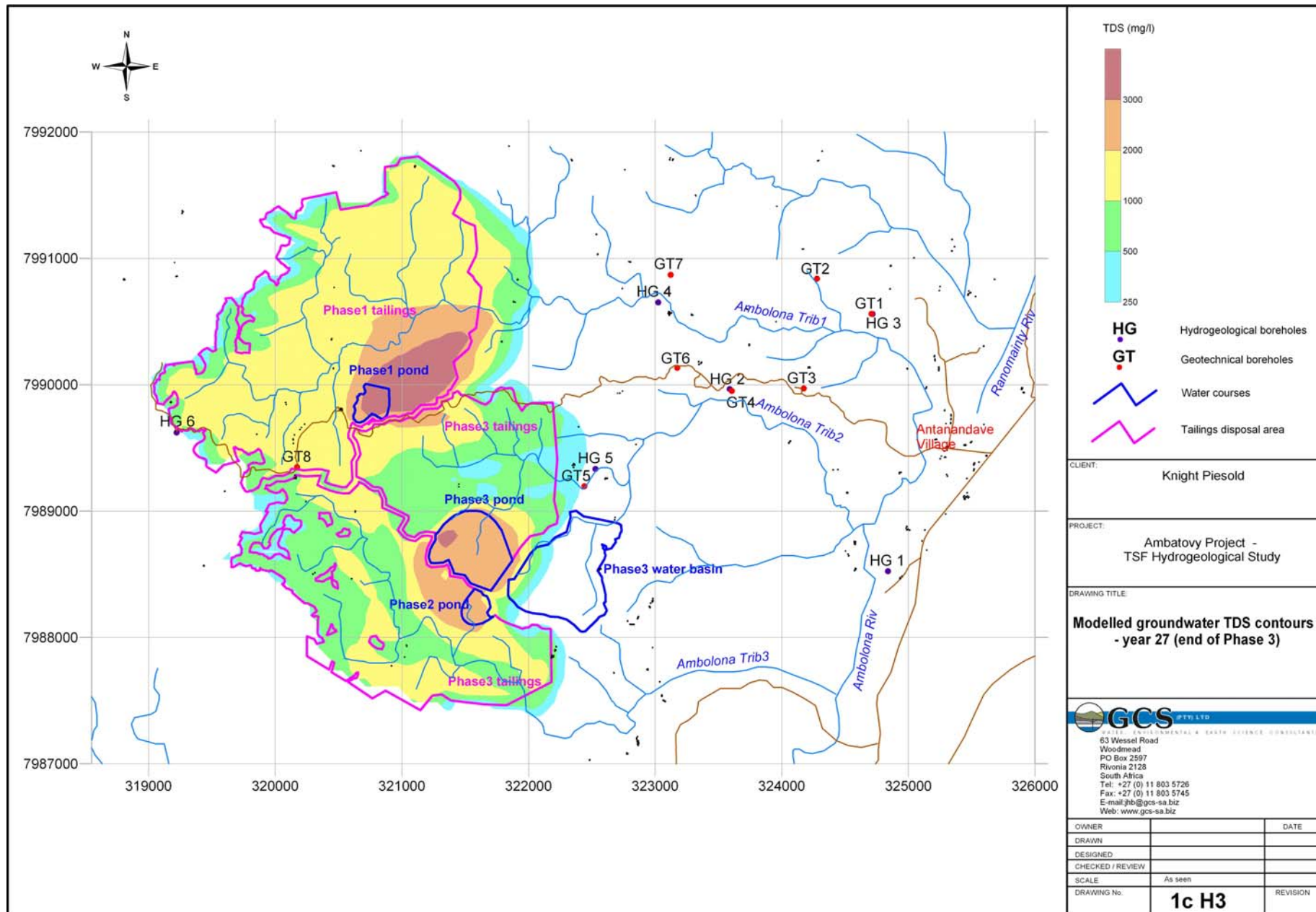


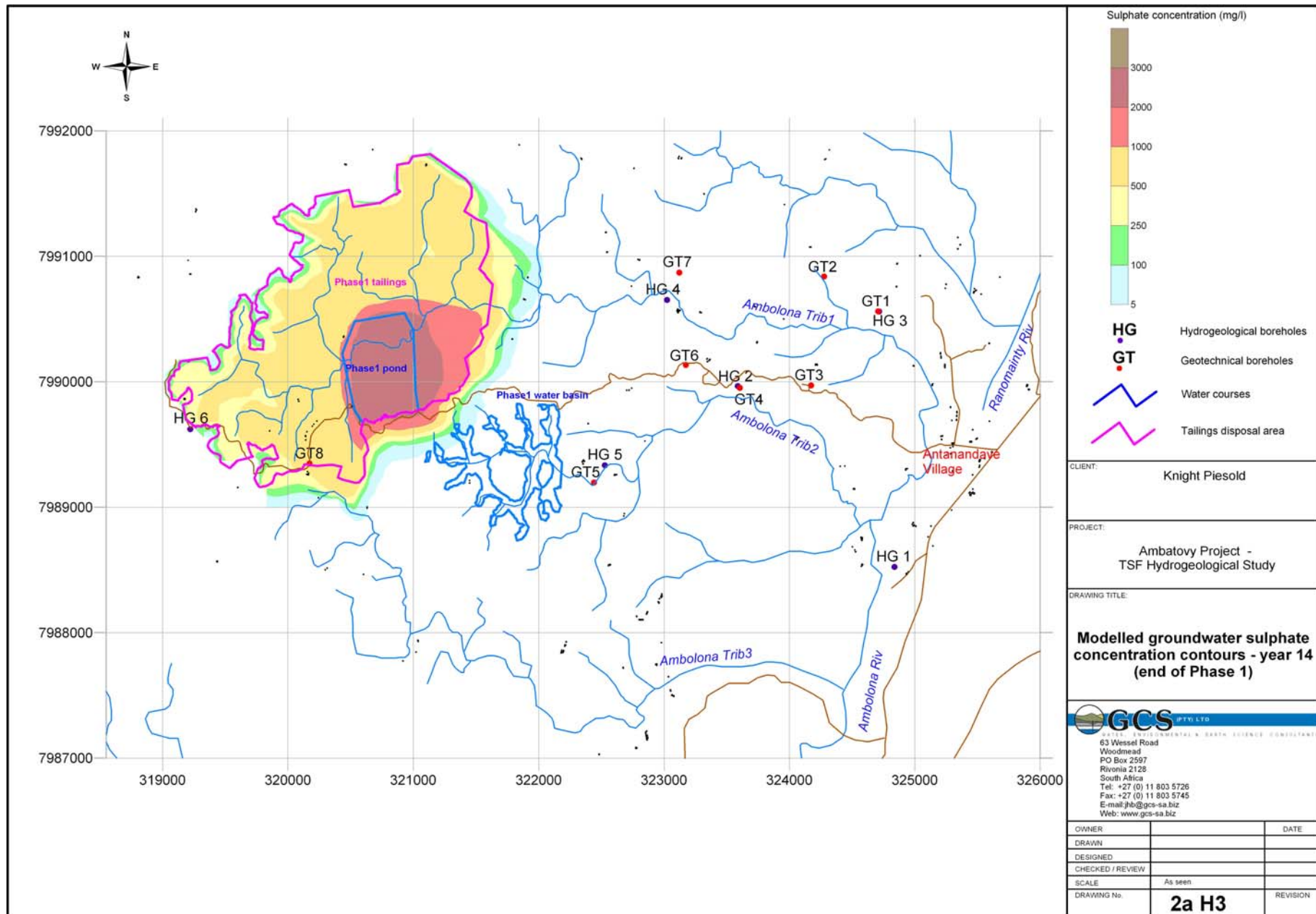


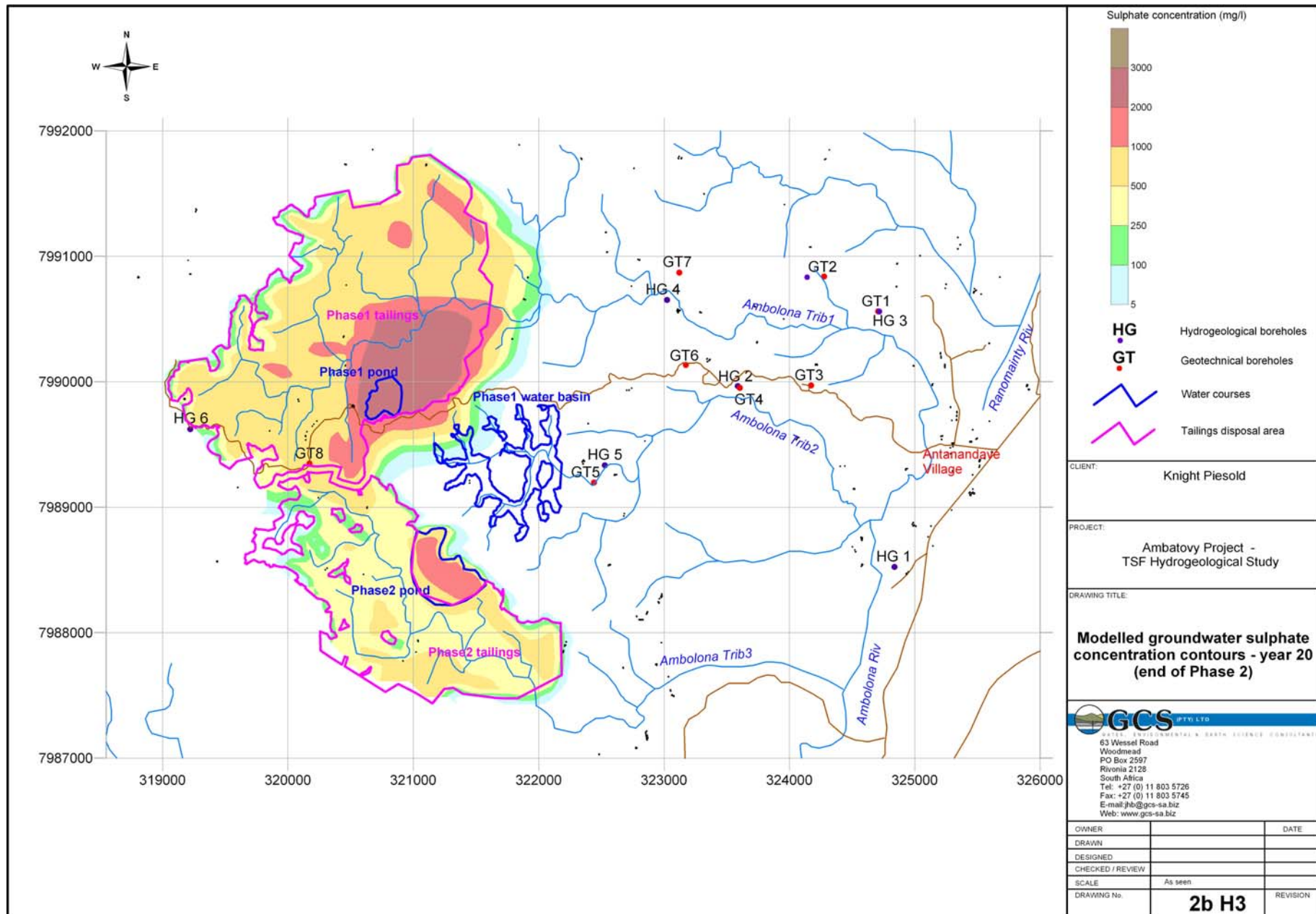
H3 - Scenario 3 Water basin lined with a synthetic line

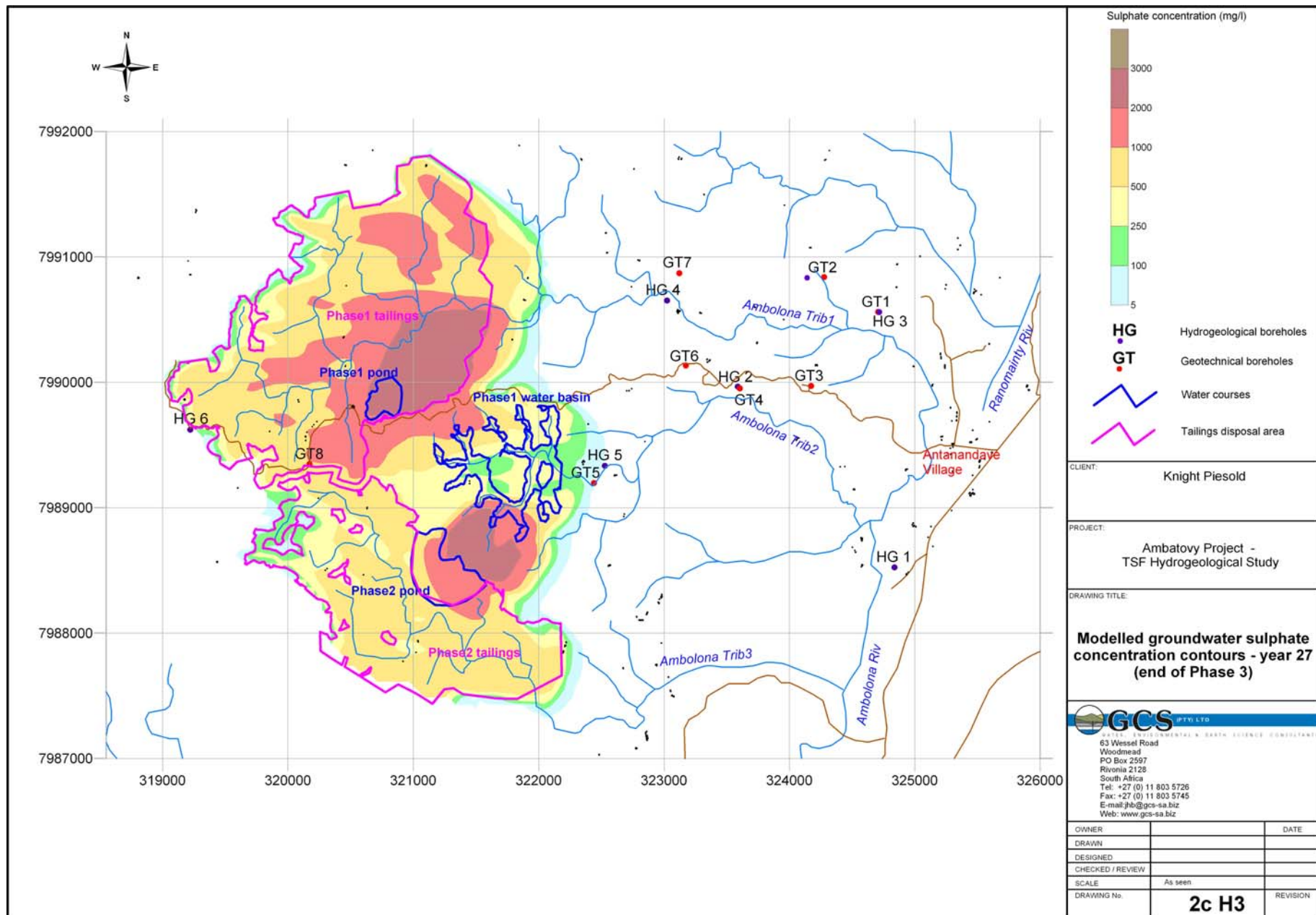


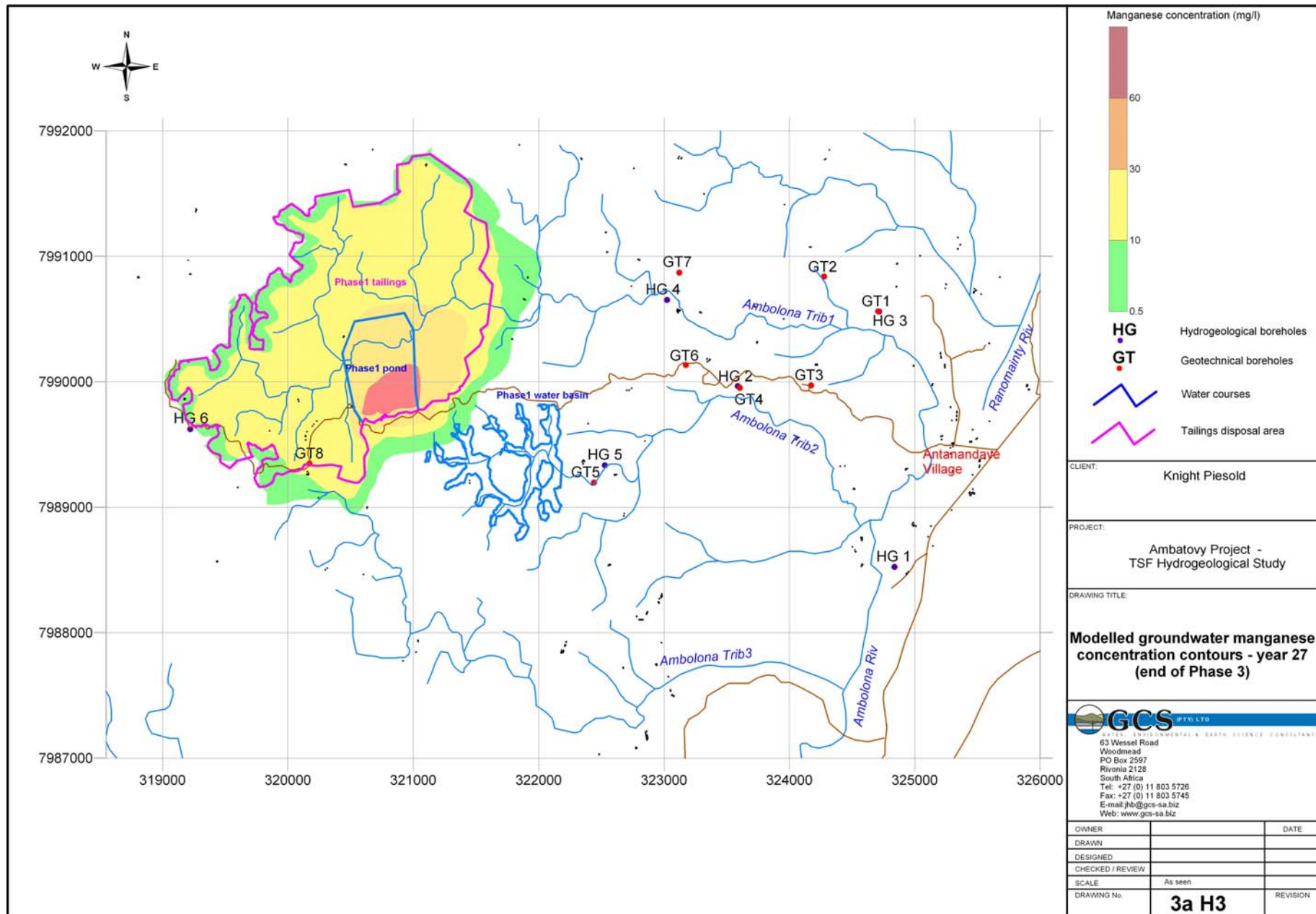


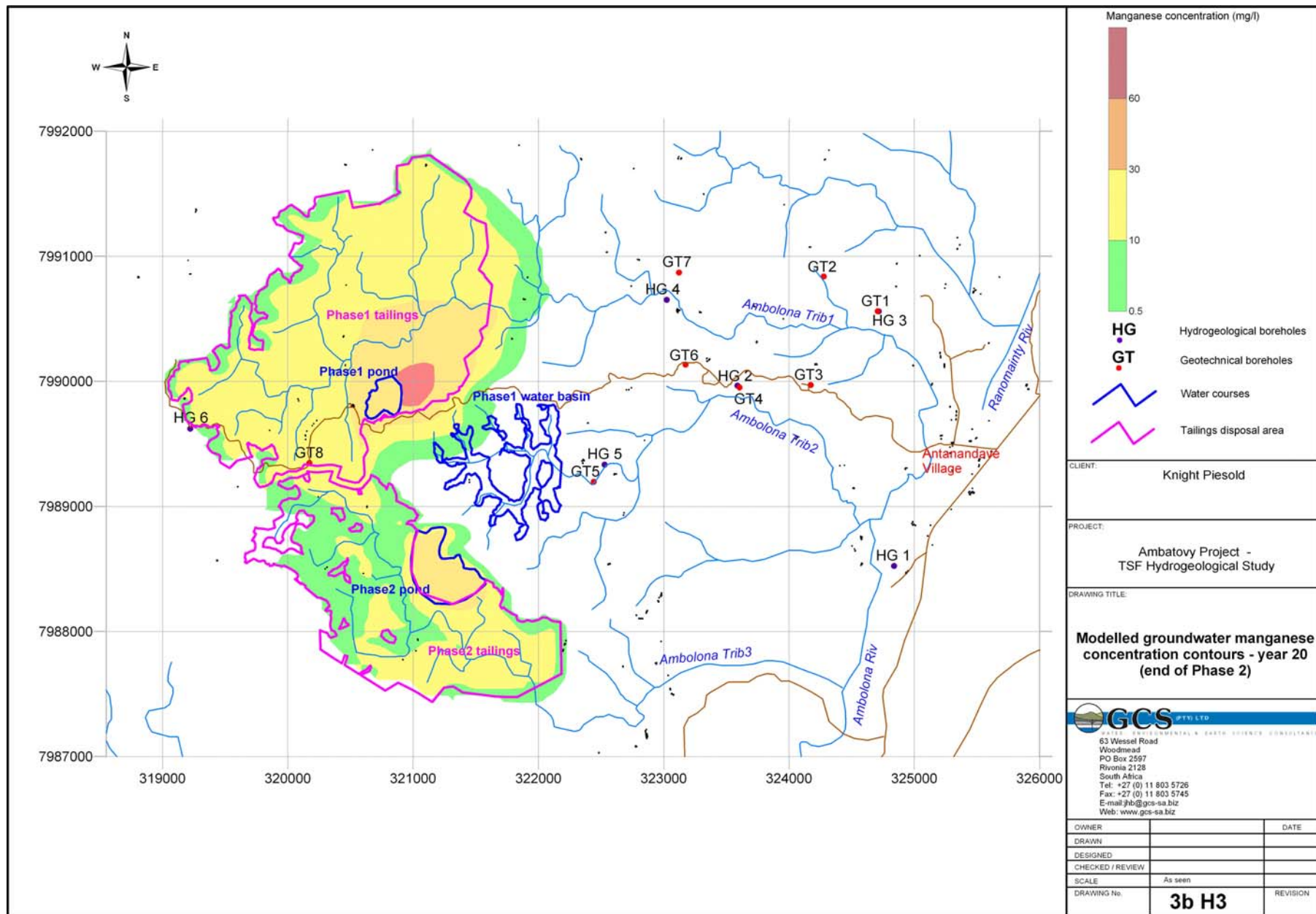


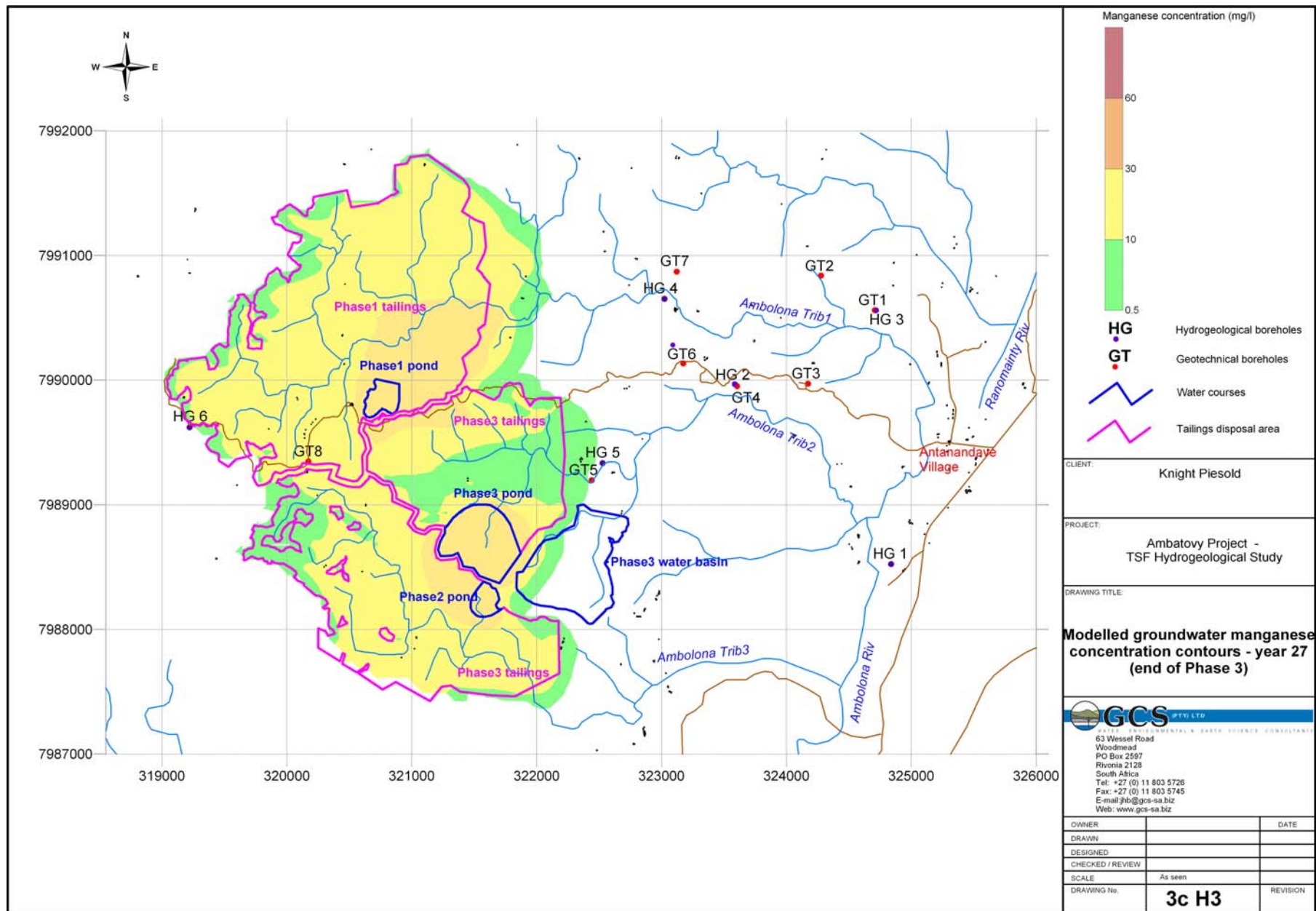




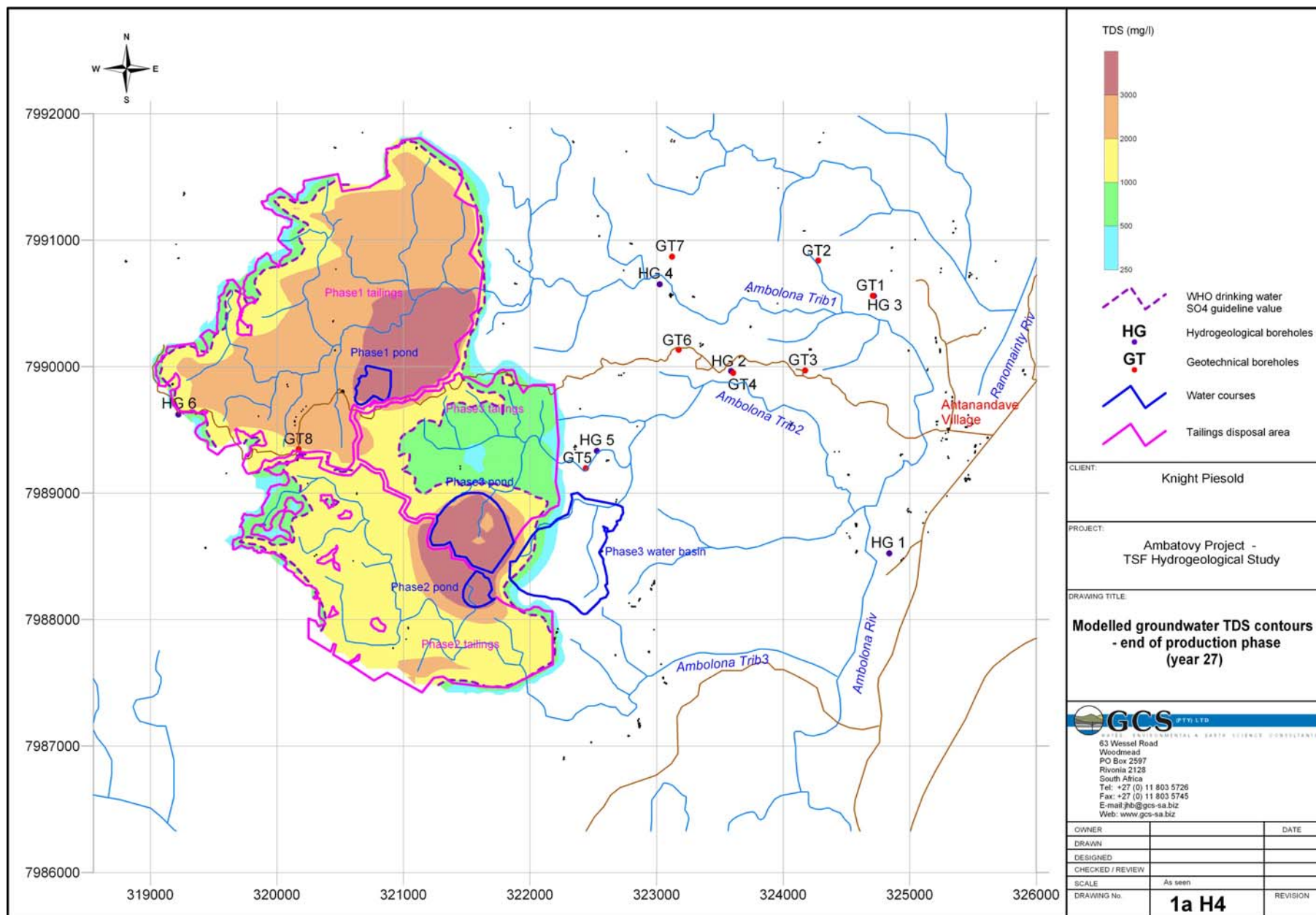


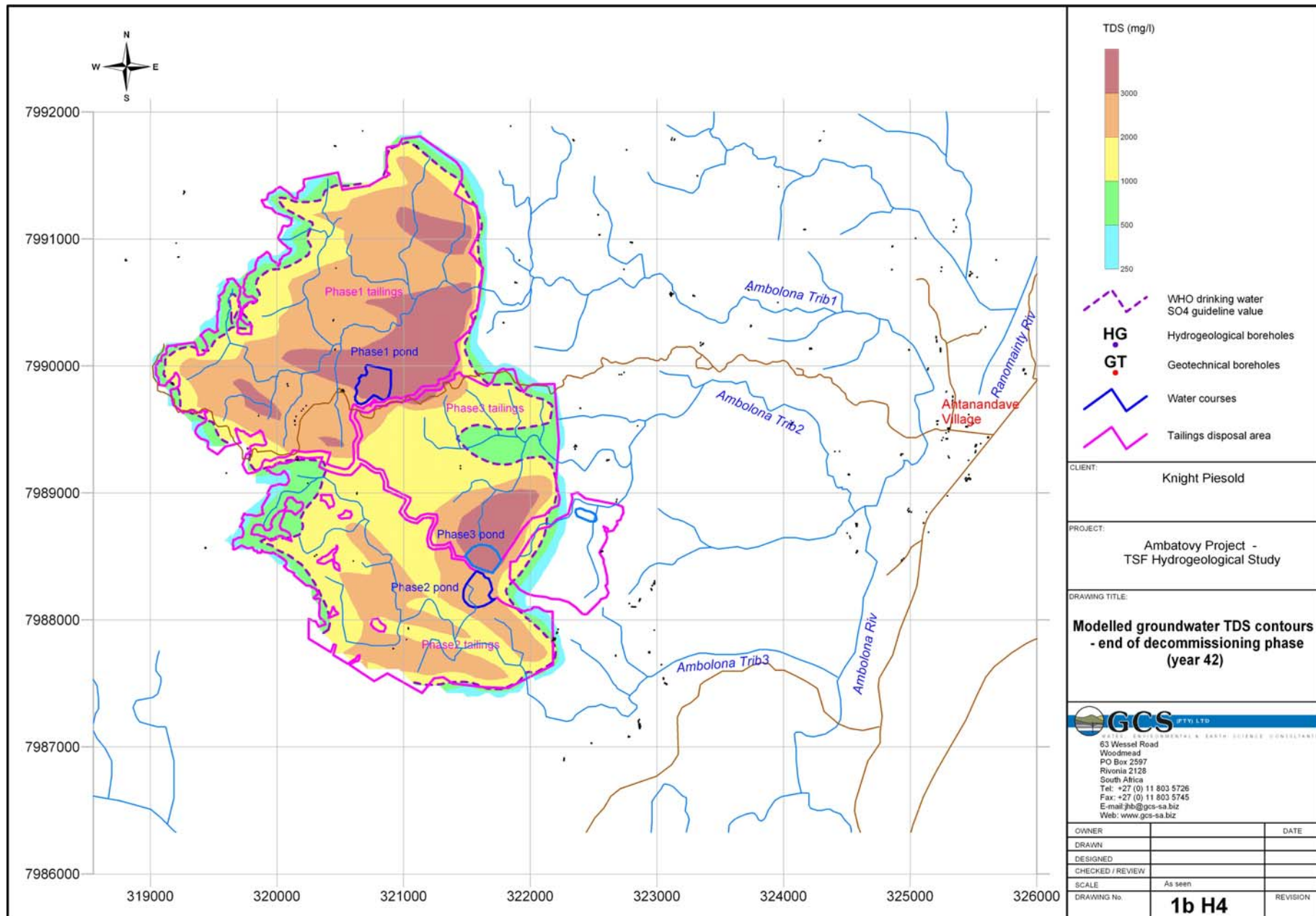


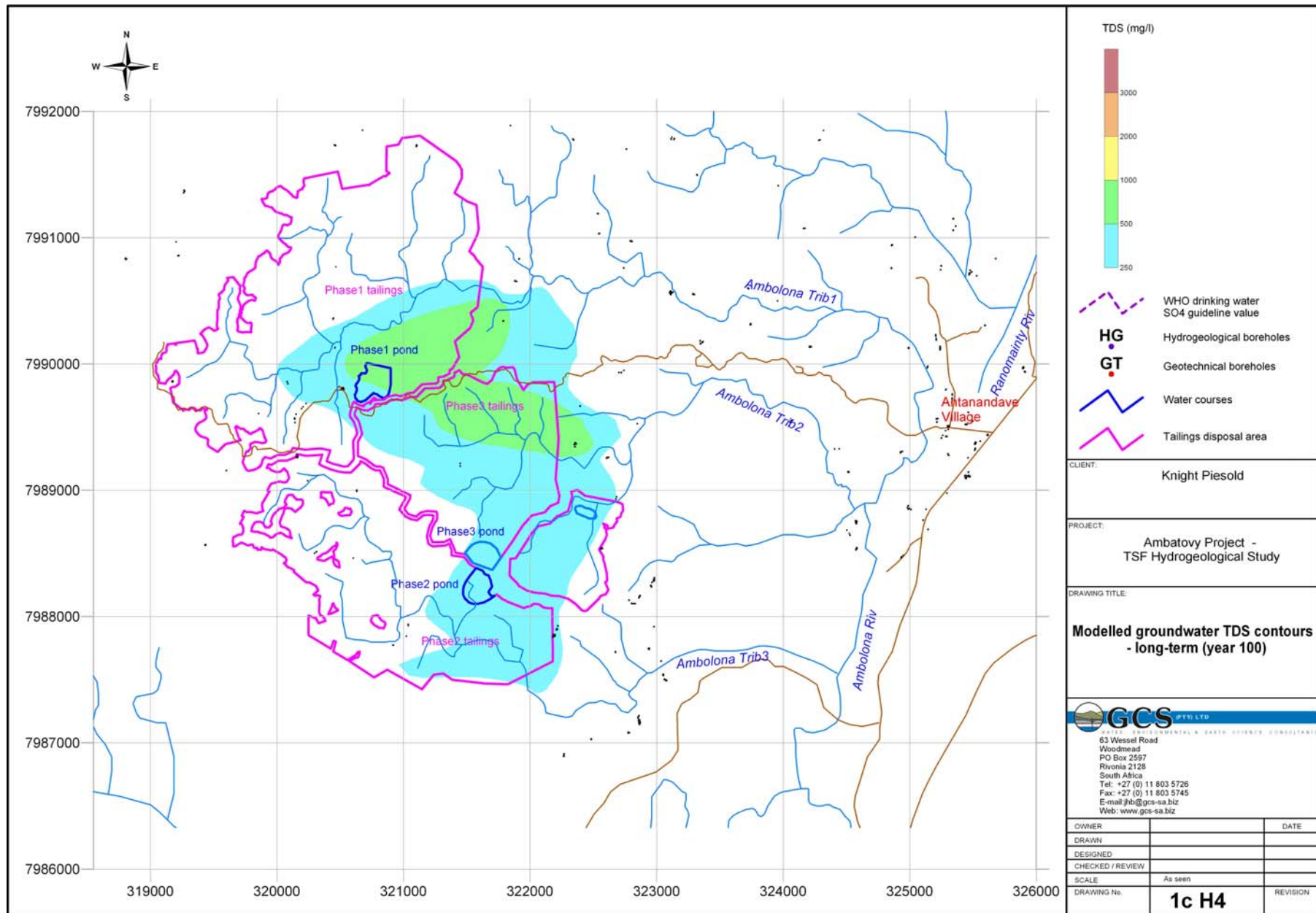


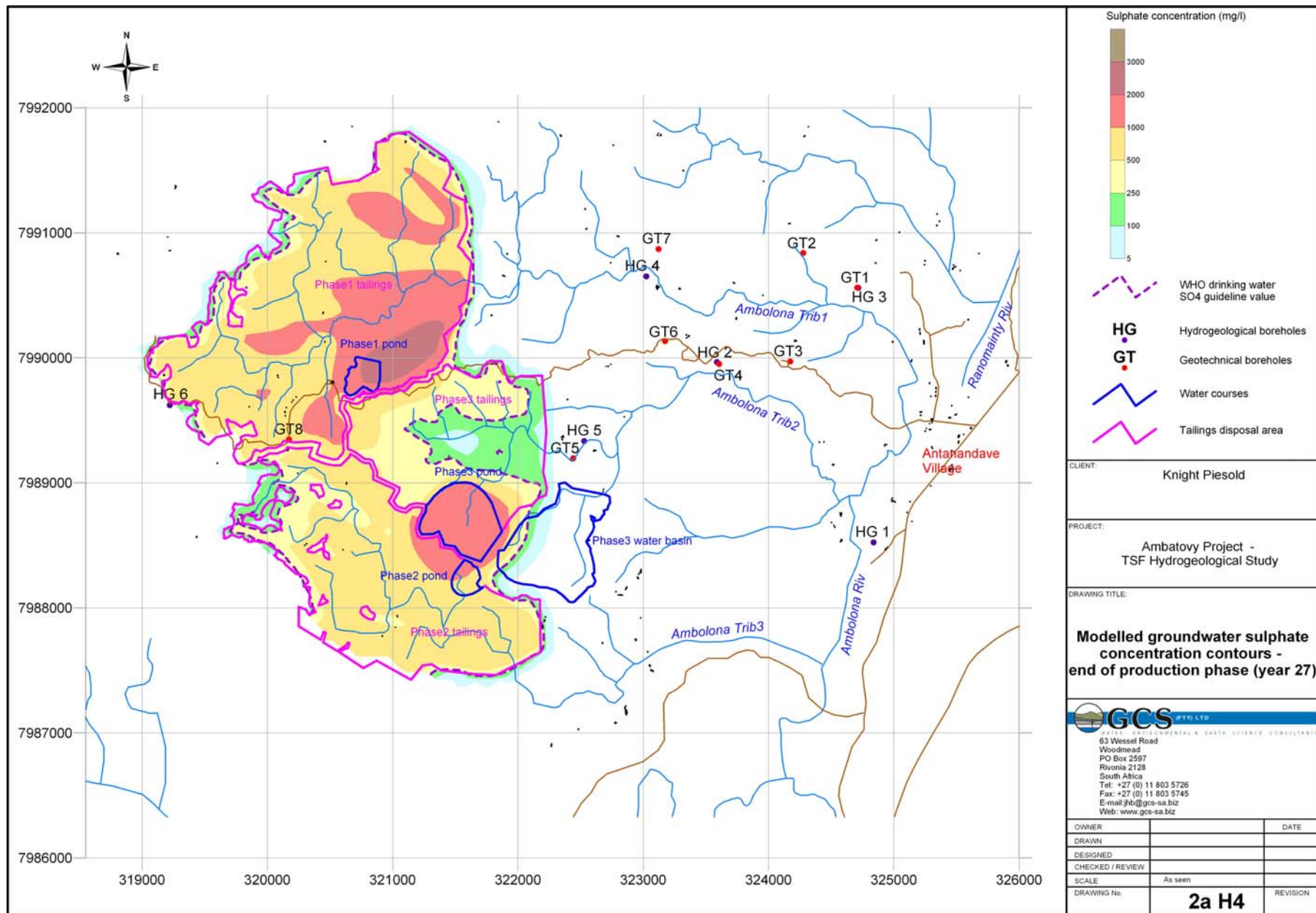


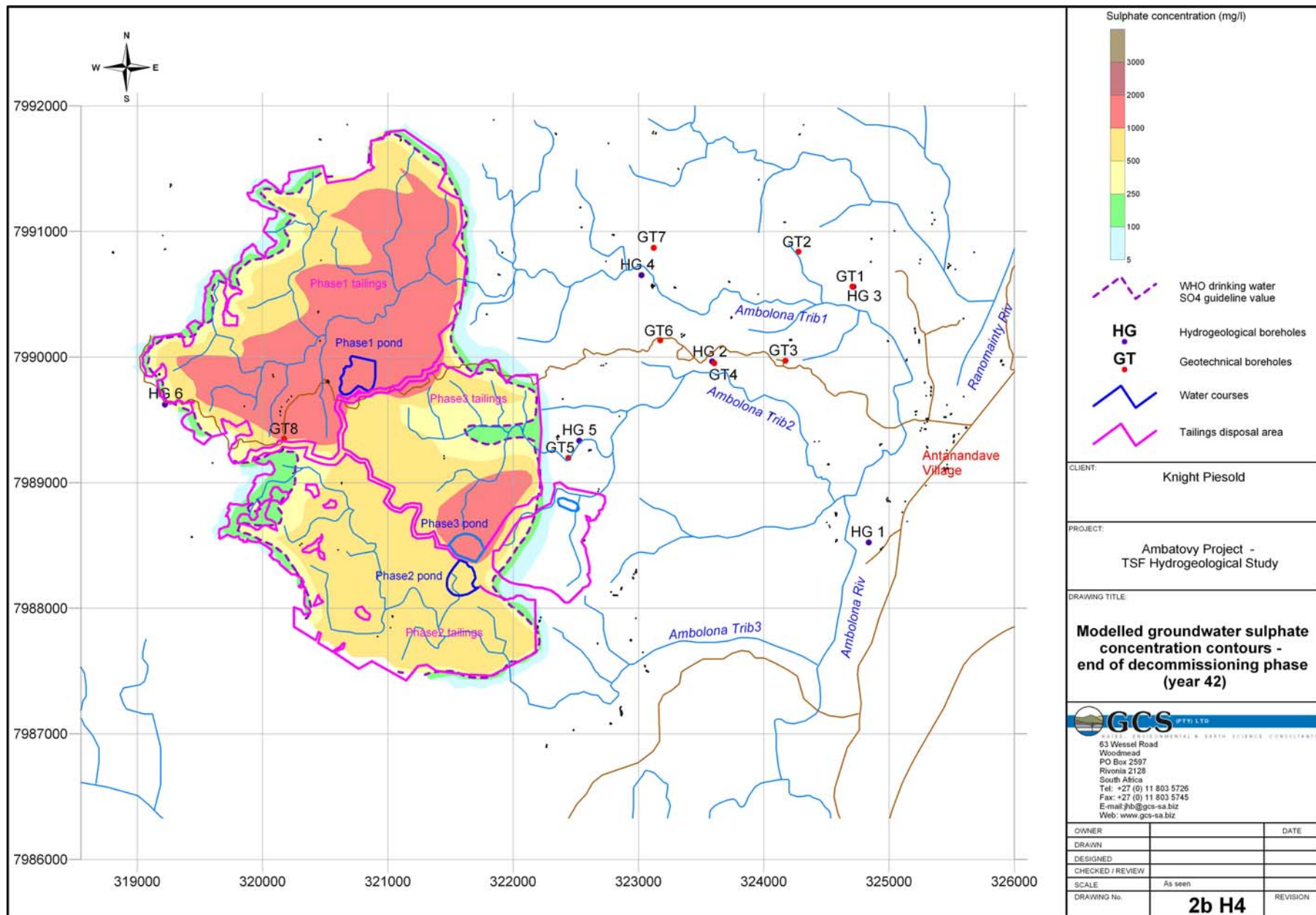
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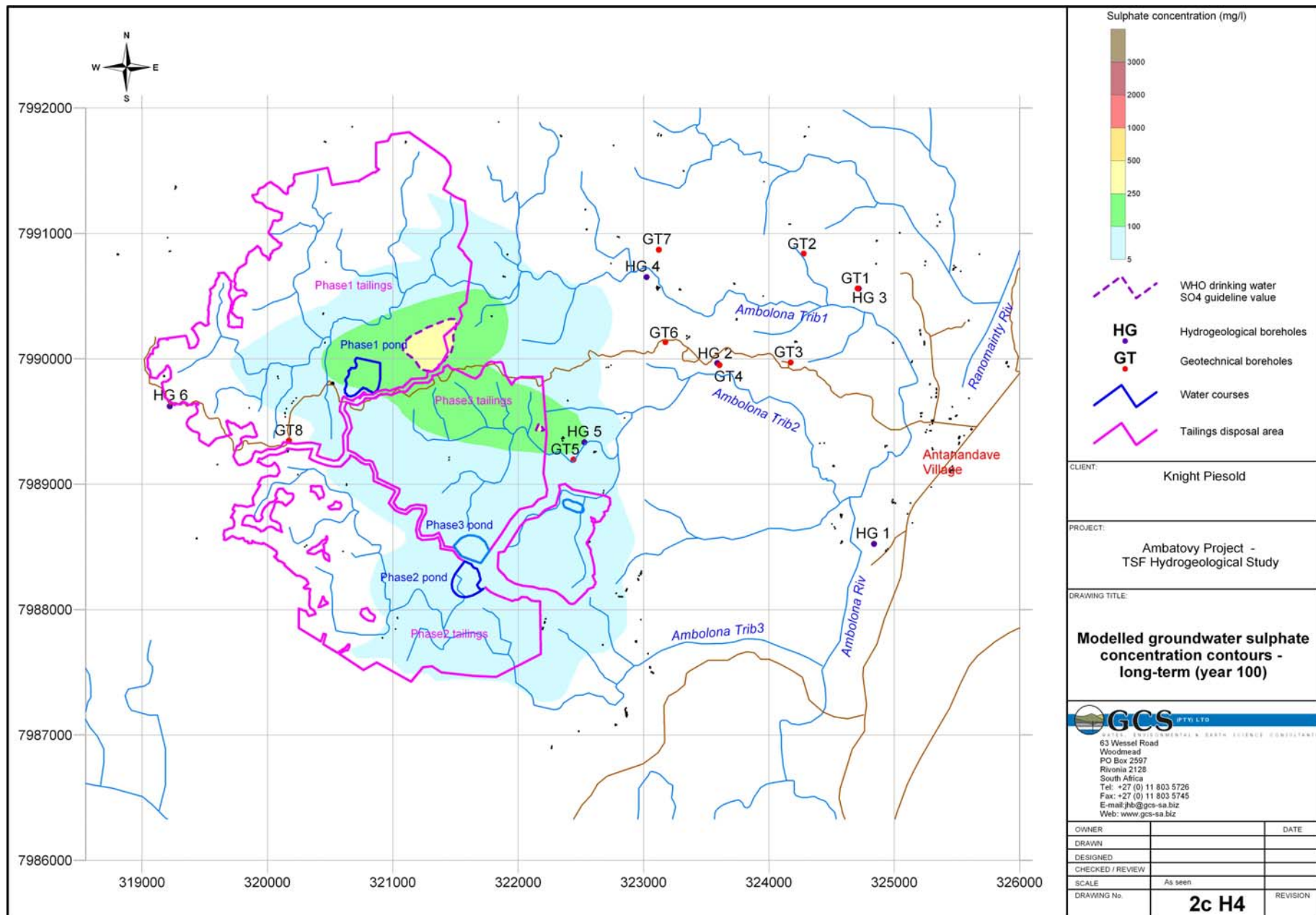


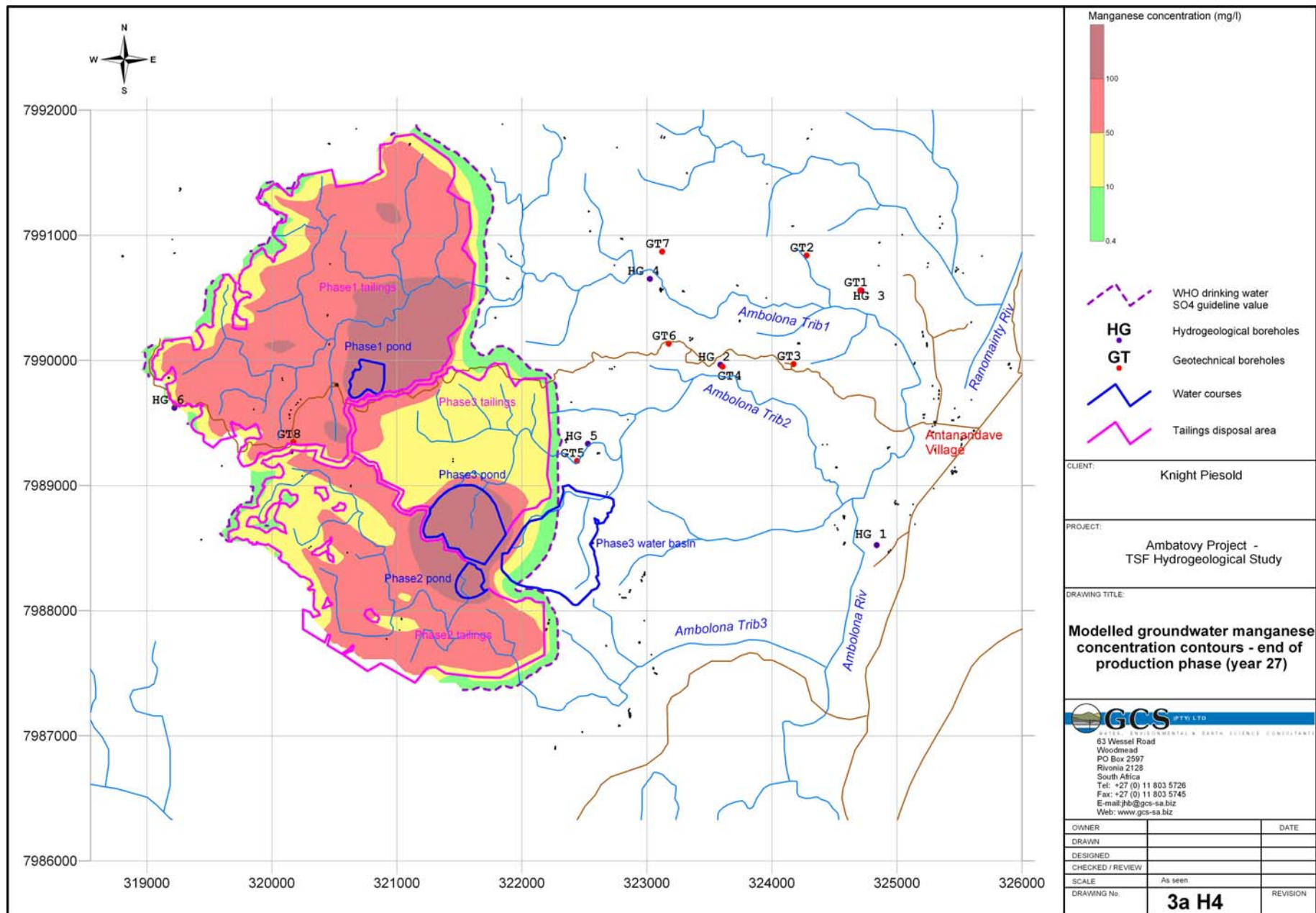


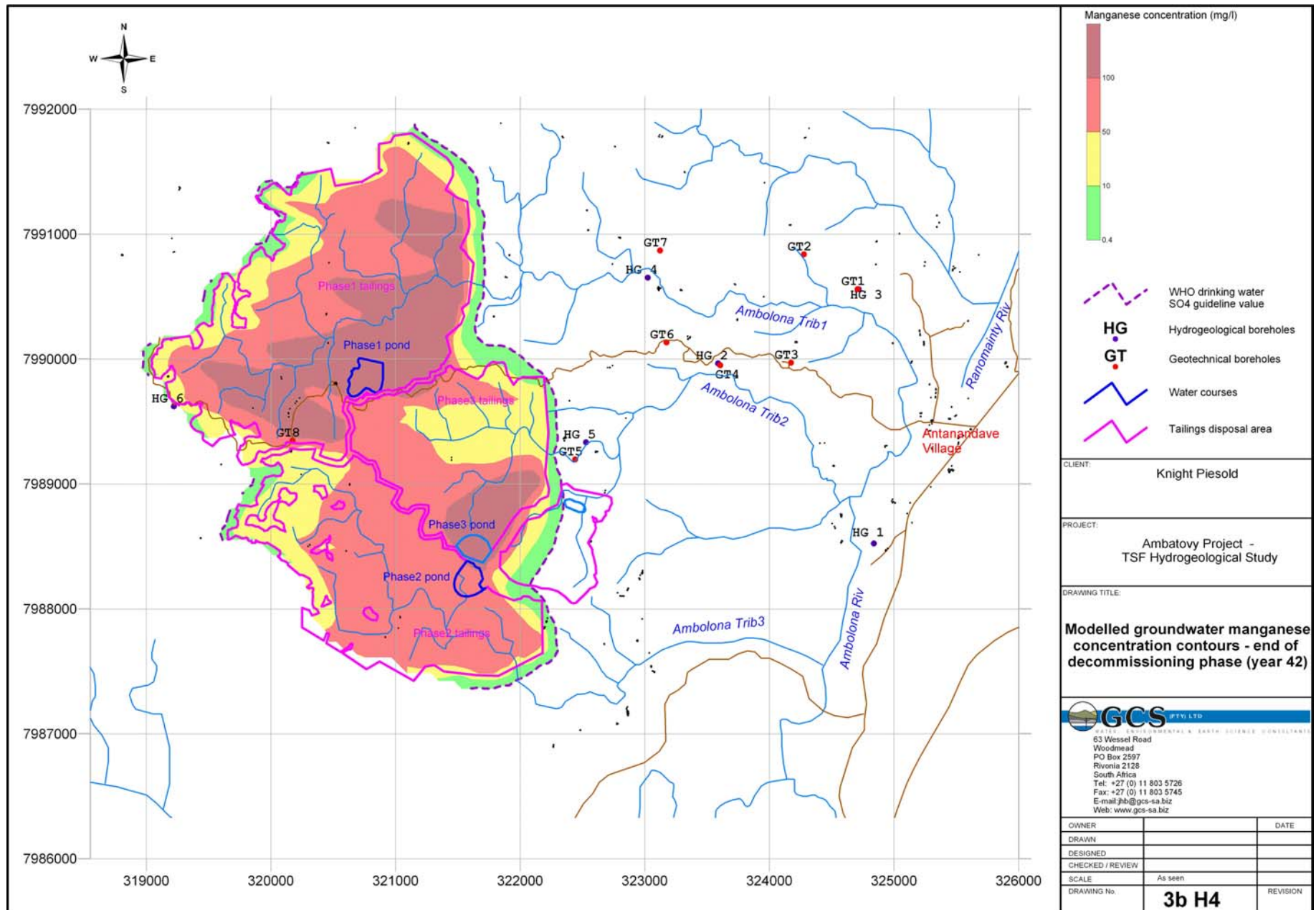


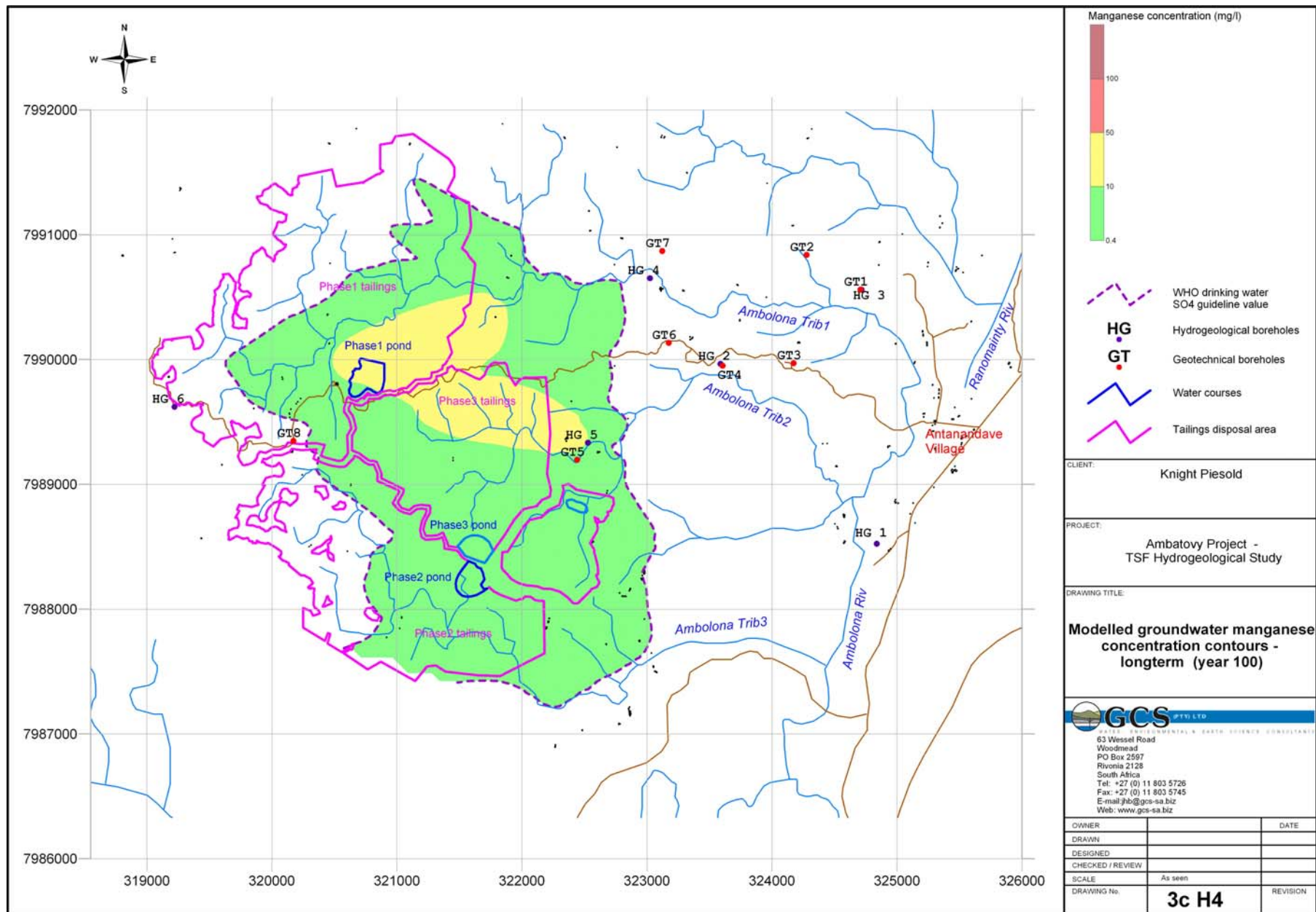




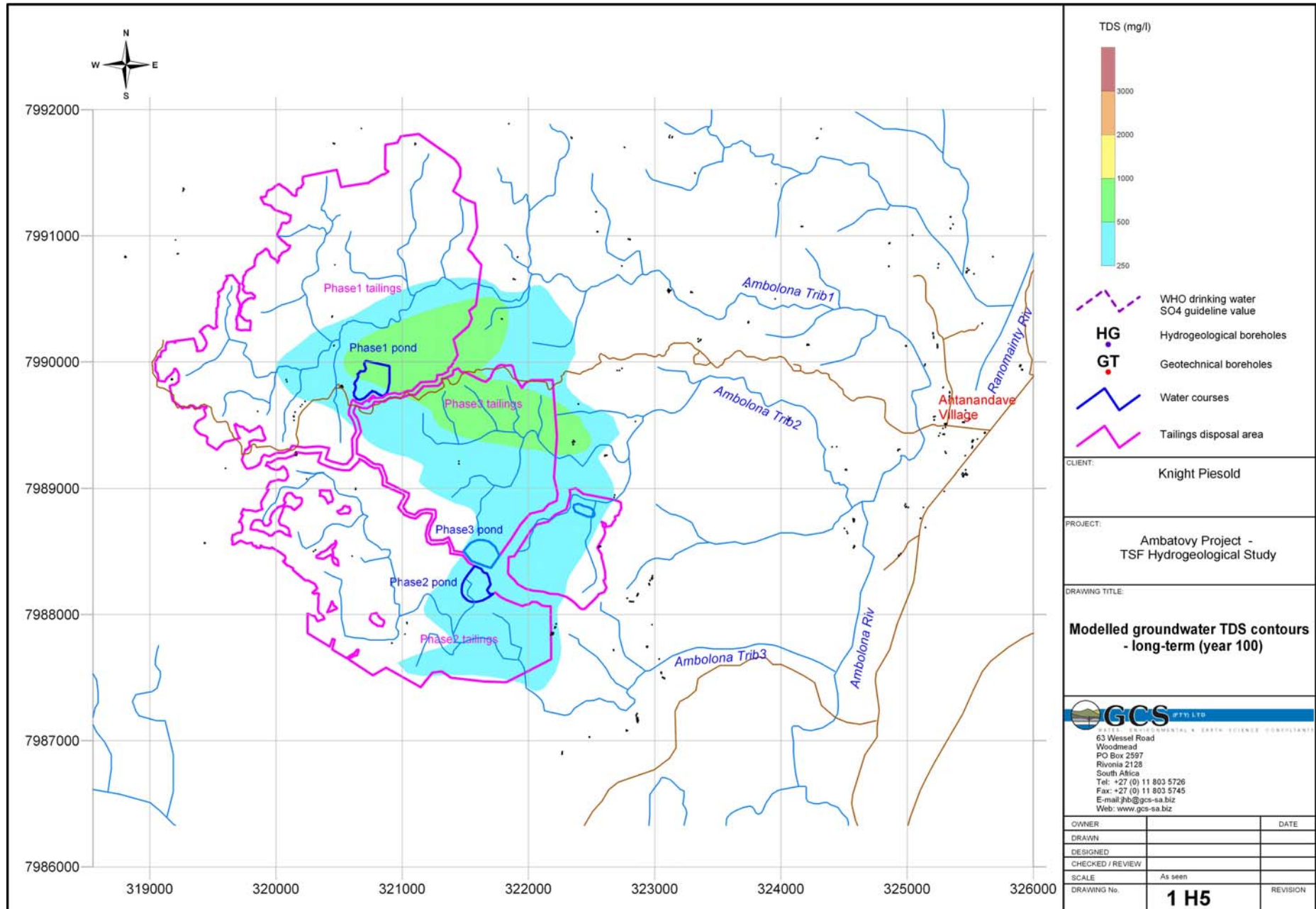


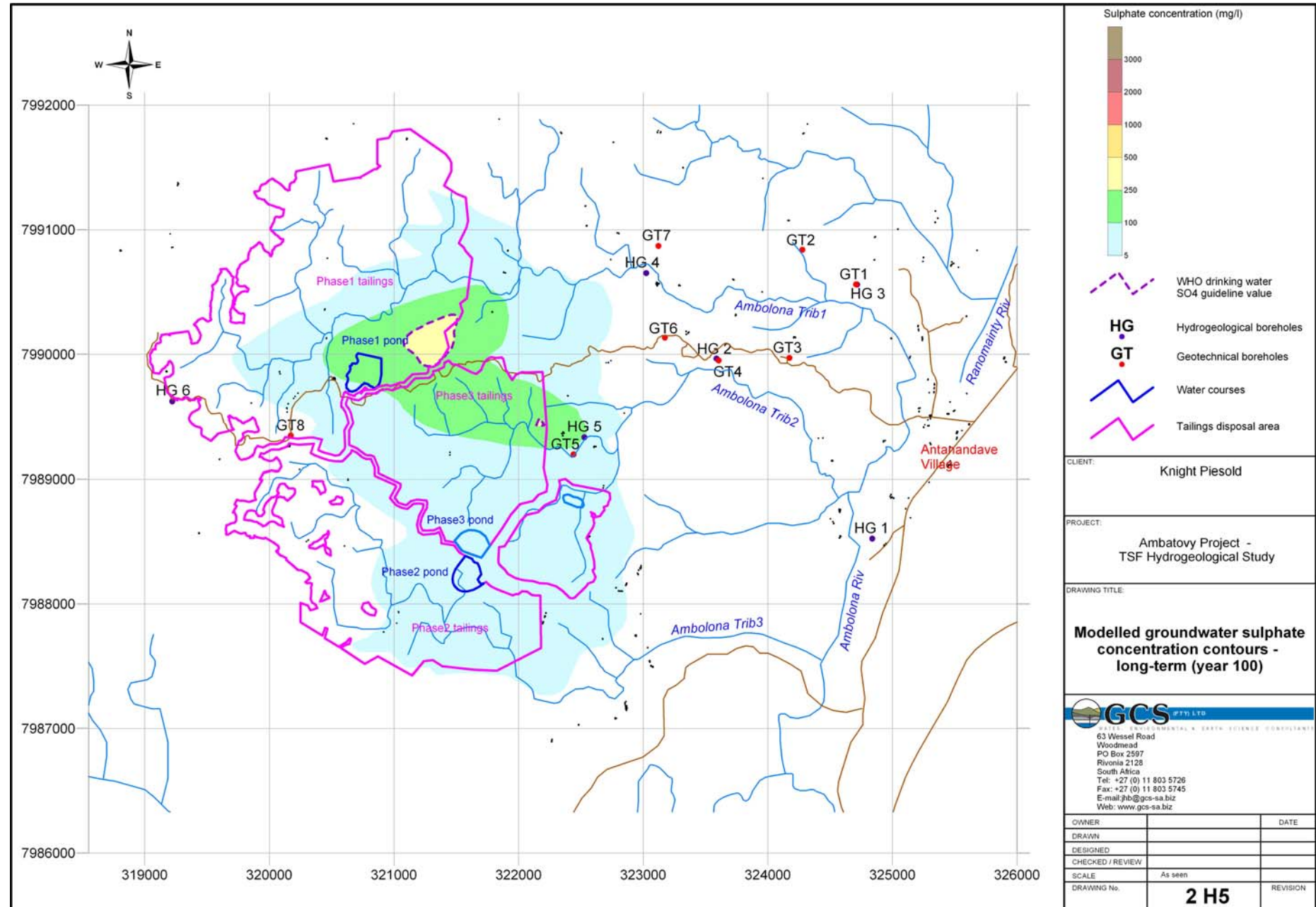


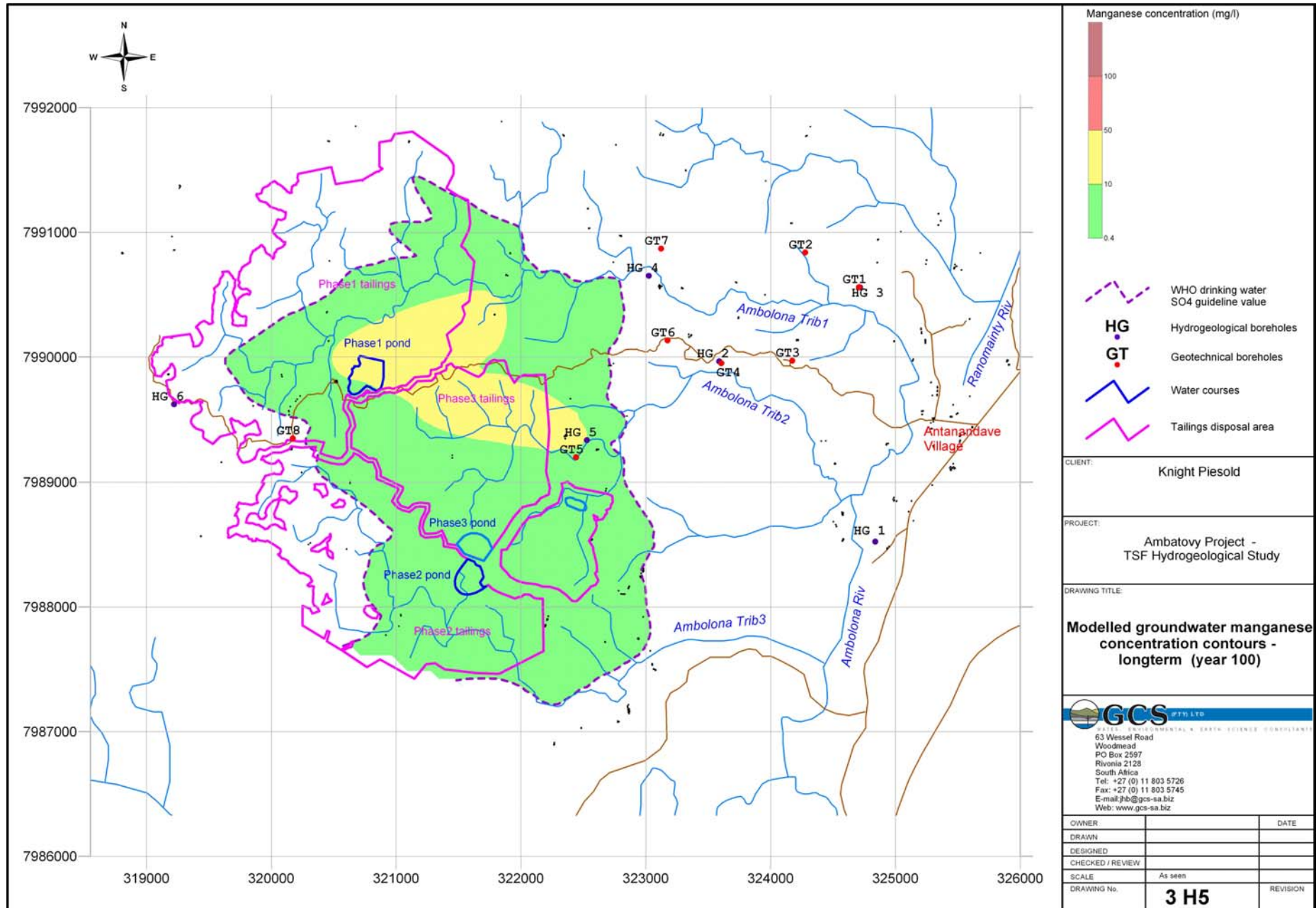




H5 – Long-term scenario







APPENDIX I: GROUNDWATER SALT LOADS

Production phase groundwater salt loads

SO₄ groundwater salt loads

Stream sections (m)	Baseline	Phase 1	Phase 2	Phase 3
	kg/day	kg/day	kg/day	kg/day
0	3.672			
250	0.297	8.11087	12.06783	19.36261
750	1.107	1.296	1.35	1.35
1250	0.432	0.459	0.459	0.459
Total A1	1.836	9.86587	13.87683	21.17161
0	2.052			
250	0.486	0.717391	1.820652	0.972
750	0.594	0.594	0.594	0.702
1250	0.378	0.405	0.405	0.405
1750	0.432	0.432	0.432	0.432
Total B1	1.89	2.148391	3.251652	2.511
0	3.213	5.059783		
250	0.351	0.351	0.702	0.729
750	0.54	0.54	0.621	0.648
Total C1	4.104	5.950783	1.323	1.377

Mn groundwater salt loads

Stream sections (m)	Baseline	Phase 1	Phase 2	Phase 3
	kg/day	kg/day	kg/day	kg/day
0	0.15232			
250	0.01232	0.7462	1.11024	1.78136
750	0.04592	0.05376	0.056	0.056
1250	0.01792	0.01904	0.01904	0.01904
Total A1	0.22848	0.819	1.18528	1.8564
0	0.08512			
250	0.02016	0.066	0.1675	0.04032
750	0.02464	0.02464	0.02464	0.02912
1250	0.01568	0.0168	0.0168	0.0168
1750	0.01792	0.01792	0.01792	0.01792
Total B1	0.16352	0.12536	0.22686	0.10416
0	0.13328	0.4655		
250	0.01456	0.01456	0.02912	0.03024
750	0.0224	0.0224	0.02576	0.02688
Total C1	0.17024	0.50246	0.05488	0.05712

Long-term groundwater salt loads

SO₄ salt loads - kg/day**Stream sections Catchment A**

Distance (m)	year 15	year 20	year 25	year 30	year 35	year 40	year 45	year 50	year 55	year 60	year 65	year 70	year 75	year 80
100	8.487	7.982	7.476	6.831	6.186	5.454	4.723	4.103	3.484	2.926	2.369	1.982	1.594	1.207
250	6.121	6.371	6.621	6.227	5.833	5.288	4.742	4.306	3.871	3.460	3.049	2.702	2.355	2.008
500	1.648	2.985	4.323	4.900	5.477	5.268	5.058	4.605	4.151	3.696	3.240	2.895	2.549	2.204
750	2.389	4.101	5.813	5.882	5.951	5.789	5.627	5.259	4.891	4.278	3.665	3.098	2.530	1.963
1000	0.148	0.148	0.148	0.148	0.148	0.183	0.254	0.380	0.506	0.572	0.638	0.611	0.583	0.556
1250	0.139	0.139	0.139	0.139	0.139	0.139	0.139	0.268	0.397	0.526	0.654	0.667	0.681	0.695

Stream sections Catchment B

Distance (m)	year 15	year 20	year 25	year 30	year 35	year 40	year 45	year 50	year 55	year 60	year 65	year 70	year 75	year 80
100	5.192	5.285	5.379	5.276	5.173	4.992	4.811	4.577	4.342	4.045	3.747	3.416	3.085	2.754
250	2.970	3.788	4.606	4.558	4.510	4.030	3.549	3.088	2.627	2.313	1.999	1.784	1.569	1.354
500	1.344	2.742	4.141	5.189	6.238	6.910	7.582	7.804	8.026	7.611	7.196	6.579	5.961	5.344
750	0.173	0.173	0.173	0.173	0.233	0.369	0.505	0.712	0.918	1.059	1.200	1.162	1.124	1.085
1000	0.137	0.137	0.137	0.137	0.137	0.810	0.137	0.150	0.166	0.181	0.197	0.204	0.212	0.219
1250	0.174	0.174	0.174	0.174	0.174	0.174	0.174	0.174	0.174	0.174	0.174	0.174	0.174	0.174

Stream sections Catchment C

Distance (m)	year 15	year 20	year 25	year 30	year 35	year 40	year 45	year 50	year 55	year 60	year 65	year 70	year 75	year 80
100	7.344	6.944	6.545	6.230	5.916	5.601	5.286	4.858	4.429	4.000	3.572	3.063	2.554	2.045
250	4.351	4.082	3.813	3.739	3.665	3.591	3.517	3.355	3.193	3.031	2.869	2.570	2.271	1.971
500	1.055	0.990	0.925	0.962	0.999	1.037	1.074	1.102	1.130	1.158	1.186	1.133	1.081	1.029
750	0.236	0.236	0.236	0.236	0.236	0.236	0.236	0.236	0.236	0.236	0.236	0.236	0.236	0.236
1000	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166
1250	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235

Mn salt loads - kg/day**Stream sections Catchment A**

Distance (m)	year 15	year 20	year 25	year 30	year 35	year 40	year 45	year 50	year 55	year 60	year 65	year 70	year 75	year 80
100	0.781	0.734	0.688	0.628	0.569	0.502	0.434	0.378	0.321	0.269	0.218	0.182	0.147	0.111
250	0.563	0.586	0.609	0.573	0.537	0.486	0.436	0.396	0.356	0.318	0.281	0.249	0.217	0.185
500	0.152	0.275	0.398	0.451	0.504	0.485	0.465	0.424	0.382	0.340	0.298	0.266	0.235	0.203
750	0.220	0.377	0.535	0.541	0.548	0.533	0.518	0.484	0.450	0.394	0.337	0.285	0.233	0.181
1000	0.006	0.007	0.008	0.009	0.010	0.017	0.023	0.035	0.047	0.053	0.059	0.056	0.054	0.051
1250	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.025	0.037	0.048	0.060	0.061	0.063	0.064

Stream sections Catchment B

Distance (m)	year 15	year 20	year 25	year 30	year 35	year 40	year 45	year 50	year 55	year 60	year 65	year 70	year 75	year 80
100	0.478	0.486	0.495	0.485	0.476	0.459	0.443	0.421	0.400	0.372	0.345	0.314	0.284	0.253
250	0.273	0.348	0.424	0.419	0.415	0.371	0.327	0.284	0.242	0.213	0.184	0.164	0.144	0.125
500	0.124	0.252	0.381	0.477	0.574	0.636	0.698	0.718	0.738	0.700	0.662	0.605	0.548	0.492
750	0.007	0.009	0.011	0.016	0.021	0.034	0.046	0.065	0.084	0.097	0.110	0.107	0.103	0.100
1000	0.006	0.006	0.006	0.006	0.006	0.009	0.012	0.014	0.015	0.017	0.018	0.019	0.019	0.020
1250	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007

Stream sections Catchment C

Distance (m)	year 15	year 20	year 25	year 30	year 35	year 40	year 45	year 50	year 55	year 60	year 65	year 70	year 75	year 80
100	0.676	0.639	0.602	0.573	0.544	0.515	0.486	0.447	0.407	0.368	0.329	0.282	0.235	0.188
250	0.400	0.376	0.351	0.344	0.337	0.330	0.324	0.309	0.294	0.279	0.264	0.236	0.209	0.181
500	0.097	0.091	0.085	0.088	0.092	0.095	0.099	0.101	0.104	0.107	0.109	0.104	0.099	0.095
750	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
1000	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
1250	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010

APPENDIX J: IMPACT ASSESSMENT CRITERIA

The significance of the impacts identified has been determined according to the following methodology, as depicted in the tables below:

Probability

Category	Description
Definite	The impact will take place regardless of any prevention plans, and mitigatory actions or contingency plans will only contain the effect.
Highly Probable	It is most likely that the impacts will occur at some or other stage of the development. Plans must be drawn up before the undertaking of the activity.
Probable	There is a possibility that the impact will occur to the extent that provisions must therefore be made.
Improbable	The possibility of the impact is very low, due either to the circumstances, design or experience.

Extent

Category	Description
Site	The impact could affect the whole, or a measurable portion of the above-mentioned property.
Local	The impacted area extends up to approximately 5 km from the project site.
Regional	The impact could affect the area including the neighbouring properties, the transport routes and the adjoining towns.

Duration

Category	Description
Short term	The impact will either disappear with mitigation or will be mitigated through a natural process in a span shorter than any of the phases.
Medium term	The impact will last up to the end of the phases, where after it will be entirely negated.
Long-term	The impact will continue or last for the entire operational life of the development, but will be mitigated by direct human action or by natural processes thereafter.
Permanent	The only class of impact that will be non-transitory. Mitigation either by man or natural process will not occur in such a way or in such a time span that the impact can be considered transient.

Intensity

Category	Description
Low	Where the impact affects the environment in such a way that natural, cultural and social functions are not affected.
Medium	Where the affected environment is altered but natural, cultural and social function and processes continue albeit in a modified way.
High	Where natural, cultural or social functions or processes are altered to the extent that they will temporarily or permanently cease.

Significance

Category	Description
No significance	The impact is not substantial and does not require any mitigatory action.
Low	The impact is of little importance, but may require limited mitigation.
Medium	The impact is of importance and therefore considered to have a negative impact. Mitigation is required to reduce the negative impacts to acceptable levels.
High	The impact is of great importance. Failure to mitigate, with the objective of reducing the impact to acceptable levels, could render the entire development option or entire project proposal unacceptable. Mitigation is therefore essential.

VOLUME I: HYDROGEOLOGY

APPENDIX 7.2

HYDROGEOLOGY EA APPENDIX

Submitted to:

Dynatec Corporation

Note: Figures used and referenced for the hydrogeology mine and tailings EA sections may be found in Appendix 7.1 in this volume in attachments 1 and 3.

VOLUME I: PHYSICAL APPENDICES

APPENDIX 8.1

HYDROLOGY BASELINE

Submitted to:

Dynatec Corporation

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Attachment 1 Hydrographs

1 INTRODUCTION

1.1 OBJECTIVES

The main objective of the water resources investigation was to evaluate baseline conditions of the surface water resources within the Ambatovy Project (the project) area. The scope of this investigation includes five project sub-areas: the mine site, the tailings facility, the plant, the port and the slurry pipeline.

Baseline conditions will be used as a frame of reference to assess impacts of proposed project activities on surface water systems. In support of this objective, the following activities were performed:

- analysis of regional climate and hydrologic (streamflow) data;
- collection and analysis of local climate data, including precipitation and evapotranspiration;
- installation of stream gauges and analysis of local streamflow data in the mine and tailings areas;
- flow measurements at a sample of streams crossed by the pipeline route; and
- development of general water balances for the mine and tailings areas.

1.2 METHODOLOGY

1.2.1 Historic Data

Information on Madagascar's climate was obtained from Battistini and Bourdieu (1969) and Chaperon et al. (1993). Regional and project area climate information was also obtained from the World Meteorological Organization (WMO) and from rainfall stations at regional railway stations.

Daily precipitation data and monthly temperature data were obtained from the Madagascar Ministry of Public Works and Transport, Meteorology Branch.

1.2.2 Short-Term Climate Data

To characterize rainfall specific to the mine site, two weather stations were installed in November 1996. One station is currently in operation near the mine site. The second weather station, which had been located in the Brickaville area is no longer operational. The stations are GroWeather™ integrated weather station and data logger installations manufactured by the Davis Instruments Corporation. The following parameters are recorded at 10-minute intervals: temperature, dew point temperature, relative humidity, precipitation, barometric pressure, solar radiation, wind speed and wind direction. Potential evapotranspiration is also calculated on an hourly basis.

1.2.3 Short-Term Streamflow Data

A hydrologic field program was initiated in February 1997 in the mine area. The program consisted of installing and collecting data from surface water gauges and weirs. The data collected were limited since all but one of the gauges were damaged or stolen.

A second, more comprehensive, data collection program was established in March 2004. Site-specific streamflow data were collected over the March 2004 to March 2005 period at 12 locations in the mine area (which include three sites on the Mangoro River), and four locations in the tailings area including the Ivondro River. Discharge and water level measurements were taken on a monthly basis by a team of technicians in order to establish a rating curve for each location. Water levels were recorded on a daily basis by local assistants and were used to derive a time series of streamflow for each station. Daily water levels continue to be recorded at these locations.

Flow measurements were taken as part of the aquatic resources field program at a sample of streams along the pipeline route (see Volume J, Section 3.1). A total of 15 streams were surveyed, 13 in September to October 2004 and two in January to February 2005.

2 REGIONAL CLIMATE AND HYDROLOGY

2.1 TEMPERATURE

2.1.1 Overview

The island of Madagascar is characteristic of tropical latitudes and experiences two main seasons. The hot season coincides with the rainy season between November and March, and the cool season is typically from April to October. The temperature variation between seasons is 6 to 8°C.

Altitude is the predominant factor affecting mean annual temperatures on the island. The temperature difference between the coast and the central plateau is roughly 13°C, but varies with latitude by only 3°C along the length of the island. The general temperature gradient is -0.7°C per 100 m rise in elevation. The east side of the island is cooler than the west and is characterized by mean annual temperatures of about 23°C. Coastal and lowland areas on the west side of the island have average annual temperatures in excess of 26°C and up to 33°C. In the central highlands, mean annual temperatures rarely exceed 23°C, with the highest locations being as cool as 16°C.

2.1.1.1 Project Areas

Mean monthly temperatures at Moramanga, Andasibe (Perinet), and Toamasina are shown in Table 8.1-1. The mean annual temperature is around 19°C at Moramanga and Andasibe (Perinet) on the central plateau, but is considerably warmer at about 25°C at Toamasina on the coast.

Temperatures along the pipeline route are expected to vary with elevation, and are expected to lie generally between temperatures at the mine site and at the tailings facility.

Table 8.1-1 Mean Monthly Temperatures (°C)

Project Area	Location	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
mine	Moramanga ^a	21.4	22.3	22.4	22.4	21.9	20.9	18.8	16.6	15.7	16.0	17.5	19.5	19.6
	Andasibe (Perinet) ^b	20.5	21.3	21.7	22.0	21.3	23.8	18.3	16.1	15.3	15.2	16.5	18.5	19.2
tailings, plant, port	Toamasina ^c	25.1	26.3	27.0	27.1	26.7	25.8	24.9	23.2	21.7	21.7	22.3	23.6	24.6

Source: Madagascar Ministry of Public Works and Transport, Meteorology Branch 2005.

Notes: Periods of record: a 1951-1980; b 1963-1973; c 1950-2004.

2.2 RAINFALL

2.2.1 Overview

Annual rainfall varies widely across the island and is primarily influenced by orographic effects (i.e., effects associated with the lifting of air on the windward side of elevated terrain). Annual rainfall totals average as little as 377 millimeters (mm) at Faux-Cap in the southern part of the island to as much as 3,792 mm at Maroantsetra in the north. At high elevations in the north, rainfall has exceeded 5,000 mm during some years.

Most rainfall occurs during the hot season, which is also considered the wet season on many parts of the island. The wettest part of the island is the east coast, particularly along the escarpment where the transition from the coastal zone to the island's central plateau occurs. Storms occur over all parts of the island and typically begin in the late afternoon and early evening. They are often characterized by high-intensity rainfall of short duration (i.e., hours).

Large rainfalls also result from tropical cyclones that occur in this part of the Indian Ocean. Cyclones cover very large areas and often affect whole regions and drainage basins. They are associated with moderate to high-intensity rainfall of longer duration (i.e., tens of hours to days) resulting in extremely large total rainfall volumes. The island of Réunion, off the east coast of Madagascar, currently holds the following world records for rainfall: 1,825 mm in 24 hours (Foc, March 15 to 16, 1952) and 1,340 mm in 12 hours (Belouve, February 28-29, 1964). Rainfall amounts in Madagascar during cyclonic events often exceed 400 mm.

2.2.2 Project Regions

Estimates of annual rainfall within the project region are provided in Table 8.1-2. In the central part of the island near the mine site, annual rainfall is on the order of 1,500 mm at Moramanga and 1,950 mm at Andasibe (Perinet). The coastal area where the tailings, plant and port facilities are located is considerably wetter with annual rainfalls of about 3,300 mm, as recorded at nearby Toamasina.

Table 8.1-2 Annual Rainfall Amounts

Area	Location	Rainfall (mm)	Period of Record
mine	Moramanga	1,468	1928-2002
	Andasibe (Perinet)	1,947	1963-1973
tailings, plant, port	Toamasina	3,343	1948-2004

Source: Government of Madagascar, Meteorology Division 2005; Rainfall Station records.

Table 8.1-3 characterizes dry and wet conditions for the region based on a frequency analysis of annual precipitation. Results of the analysis indicate an annual rainfall of about 880 mm at Moramanga for 1:50 year dry conditions. This is equivalent to roughly 60% of the mean annual amount. Similarly, for 1:100 year wet conditions, the annual rainfall at Toamasina would be about 5,280 mm, or 161% of the mean annual amount.

Monthly precipitation characteristics are shown in Table 8.1-4 for the regional climate stations.

Daily rainfall data from the stations were analyzed to determine the maximum daily rainfall amounts associated with various return periods. These amounts are summarized in Table 8.1-5. Daily rainfall is measured between 7 AM and 7 AM, and therefore the maximum values provide only an approximation of maximum 24-hour totals. The maximum 24-hour amount for a given return period would be slightly greater than the daily maximum value for the same period.

As mentioned previously, Madagascar is subject to cyclones from the Indian Ocean where large amounts of rainfall occur over a short period. Some examples of extreme precipitation are provided in Table 8.1-6.

Table 8.1-3 Annual Precipitation Frequency Analysis

Area	Location	Dry Years					Mean Annual	Wet Years					Period of Record	Distribution
		100	50	20	10	5		5	10	20	50	100		
Annual Precipitation (mm)														
mine	Moramanga ^(a)	804	877	989	1,092	1,219	1,475	1,747	1,896	2,023	2,169	2,269	1927-2002	3-PLN
	Andasibe (Perinet) ^(a)	1,295	1,396	1,537	1,651	1,777	1,987	2,159	2,237	2,296	2,357	2,394	1963-1973	3-PLN
	Mangoro Gare ^(b)	734	827	967	1092	1,244	1,536	1,828	1,982	2,110	2,254	2,350	1950-1982 (17)	3-PLN
tailings, plant, port	Toamasina ^(a)	2,200	2,294	2,448	2,600	2,804	3,272	3,858	4,221	4,556	4,974	5,279	1948-2004	3-PLN
Annual Precipitation (% of mean annual)														
mine	Moramanga ^(a)	55%	59%	67%	74%	83%	100%	118%	129%	137%	147%	154%	1960-1991	3-PLN
	Andasibe (Perinet) ^(a)	65%	70%	77%	83%	89%	100%	109%	113%	116%	119%	120%	1963-1973	3-PLN
	Mangoro Gare ^(b)	48%	54%	63%	71%	81%	100%	119%	129%	137%	147%	153%	1950-1982 (17)	3-PLN
tailings, plant, port	Toamasina ^(a)	67%	70%	75%	79%	86%	100%	118%	129%	139%	152%	161%	1948-2004	3-PLN

Source: ^(a) Madagascar Ministry of Public Works and Transport, Meteorology Branch 2005.

^(b) Railway station rainfall records.

Notes: Numbers shown in brackets indicate number of years of data.

3-PLN = 3 parameter log-normal distribution.

Numbers have been rounded for presentation purposes.

Table 8.1-4 Mean Monthly Rainfall Amounts (mm)

Area	Station	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total	Period
mine	Moramanga ^(a)	135	259	291	261	194	66	47	42	52	50	25	47	1,468	1928-2002
	Andasibe (Perinet) ^(a)	138	284	388	278	260	106	58	74	127	119	50	66	1,947	1963-1973
	Mangoro Gare ^(b)	210	280	270	207	220	58	34	29	44	36	16	47	1,454	1950-1982
tailings, plant, port	Toamasina ^(a)	155	311	403	425	479	315	271	263	276	200	128	116	3,343	1948-2004

Source: ^(a) Madagascar Ministry of Public Works and Transport, Meteorology Branch 2005.

^(b) Railway station rainfall records.

Notes: Numbers have been rounded for presentation purposes.

Table 8.1-5 Maximum Daily Precipitation Frequency Analysis

Area	Location	Maximum Daily Precipitation (mm)						Period of Record	Years of Data	Distribution
		2-yr	5-yr	10-yr	20-yr	50-yr	100-yr			
mine	Moramanga	89	128	157	187	231	268	1934-2000	49	LP3
	Andasibe (Perinet)	113	168	214	266	346	419	1963-1973	10	LP3
tailings, plant, port	Toamasina	159	224	273	326	402	465	1948-2004	55	LP3

Source: Madagascar Ministry of Public Works and Transport, Meteorology Branch 2005

Note: Daily precipitation totals are from 7 am to 7 am.

LP3- log pearson III distribution.

Numbers have been rounded for presentation purposes.

Table 8.1-6 Extreme Precipitation

Area	Location	Rainfall (mm)	Duration	Date	Source
mine	Moramanga	267	1 day	March 12, 1975	(a)
		280	24 hours	February 15, 1938	(b)
	Andasibe (Perinet)	259.2	24 hours	March 2, 1937	(b)
		265.5	1 day	March 8, 1964	(a)
tailings, plant, port	Toamasina	552	1 day	May 11, 2002	(a)
		814	2 days	May 10-11, 2002	(a)
		997	3 days	May 9-11, 2002	(a)
	Belouve, La Reunion	1,350 ^(d)	12 hours	Feb 28-29, 1964	(c)
	Vatomandry	543	24 hours	April 8, 1963	(b)
	Fenerive	333.5	24 hours	March 17, 1959	(b)
	Cilaos, La Reunion	1,880	24 hours	March 15-16, 1952	(c)
		3,860	5 days	March 13-18, 1952	(c)

Source: (a) Madagascar Ministry of Public Works and Transport, Meteorology Branch 2005.

(b) Chaperon et al. 1993.

(c) Van der Leeden et al. 1990.

(d) World record rainfall. No comparable rainfall has been recorded on Madagascar, but these values are likely appropriate for a probable maximum precipitation (PMP), since the cyclones that produced them could also strike the Toamasina area.

2.3 HUMIDITY

2.3.1 Overview

Located in the tropics, Madagascar's climate is humid and is characterized by average annual relative humidities of about 85% on the east coast and 60% on the west side of the island. The diurnal variation in relative humidity typically reaches a maximum of 85 to 95%, and can be close to 100% at daily maximum

values. Relative humidity is typically lowest in September and October, however, minimums can occur in July and August at some locations along the west coast.

2.3.2 Project Regions

Annual average relative humidity is 76% at Moramanga and Antananarivo, and 80% at Toamasina (Chaperon et al. 1993). Annual average dew points are 13.8°C at Antananarivo and 21.2°C at Toamasina (WMO data 1995 to 2003).

2.4 EVAPORATION

2.4.1 Overview

Evaporation can be estimated using a number of standardized methods. Pan evaporation uses a pan filled with water, and measures the decrease in water volume over time. Besides moisture deficit, climate variables such as solar radiation and wind speed affect the amount of amount and rate of evaporation from the pan. Piche evaporation involves a glass tube filled with water which is open at one end. Water is evaporated from a filter paper (piche) at the open end, and represents latent evaporation, i.e., the moisture deficit in the air.

Few evaporation and evapotranspiration studies have been conducted in Madagascar. The available information was reviewed by Chaperon et al. (1993) and suggests that annual pan evaporation varies from roughly 2,900 mm in the northwest, to about 1,500 mm in the central plateau, to about 1,000 mm on the eastern side of the escarpment. Actual open water evaporation is typically less than pan evaporation. Chaperon et al (1993) suggested a coefficient of 0.7 for estimating free surface evaporation based on pan evaporation. The coefficient was based on very limited data but was considered to be comparable with values used in other African countries. Rough estimates of annual open water evaporation are therefore as follows: 2,000 mm in the northwest, 1,600 mm in the south, 1,400 mm in the southwest, 1,000 to 1,100 mm in the central plateau, and 700 mm on the eastern side of the escarpment.

Evapotranspiration (ET) is the measure of total evaporation from all water, soil, vegetation and other surfaces, as well as transpiration by vegetation. This parameter is strongly associated with vegetation type and the soil moisture available to plants. ET is generally less than pan evaporation for the same location since water is not always readily available as is assumed with pan evaporation.

Actual ET compared to potential ET is close to 100% on the eastern side of the island where moisture is typically plentiful. This ratio diminishes progressively to the west, as moisture becomes limited and potential ET is higher due to hotter temperatures. Actual ET is estimated to be 70 to 80% of potential ET on the high plateau and 50 to 60% on the west coast. ET is lowest in the southern part of Madagascar, with annual estimates varying between 350 mm and 750 mm. Other annual estimates of actual ET are as follows: 1,000 mm to 1,300 mm for the eastern portion of the island, 700 to 900 mm on the high plateau, and 850 to 1,200 mm in the north-west and western regions.

2.4.2 Project Regions

Available pan evaporation data for Andasibe (Perinet) and piche evaporation data for Toamasina are summarized in Tables 8.1-7 and 8.1-8. The annual pan evaporation total of 917 mm for Andasibe provides an estimate of potential ET of about 1,000 mm/y and an estimate of open water (lake) evaporation of about 700 mm/y based on a pan coefficient of 0.7.

The annual piche evaporation of 721 mm at Toamasina represents the moisture deficit in the air but cannot be directly converted to ET or lake evaporation. Chaperon et al (1993) developed the following relationships between piche and pan evaporation for Antananarivo and Andasibe (Perinet):

$$\begin{array}{ll} \text{Antananarivo:} & E_{\text{pan}} = 1.83 E_{\text{piche}} + 0.74 \text{ (mm/day)} \\ \text{Andasibe (Perinet):} & E_{\text{pan}} = 1.80 E_{\text{piche}} + 0.54 \text{ (mm/day)} \end{array}$$

While not directly applicable to Toamasina, the relationships suggest that pan evaporation at Toamasina is about 1,500 to 1,600 mm/y. If a correction factor of 0.7 is applied, lake evaporation can be estimated at about 1,100 mm/y.

The above evaporation amounts are consistent with estimates of evapotranspiration summarized in Table 8.1-9, as provided by Chaperon et al. (1993). Specific estimates of actual ET for the project regions include 902 mm/y at Moramanga and 1,275 mm/y at Toamasina (Atlas de Madagascar in Chaperon et al. 1993).

2.5 STREAMFLOW AND RUNOFF

2.5.1 Overview

Surface water runoff varies considerably throughout Madagascar, and depends primarily upon annual precipitation, topography and vegetation cover. Chaperon et al (1993) found that the greatest runoff is recorded in streams flowing through the eastern portion of the island, where annual runoff averages from 1,300 to 2,000 mm over the entire watershed. Locations in the south have the lowest runoff, ranging from 50 to 150 mm, as calculated from gauge data collected at these locations.

Table 8.1-7 Monthly Pan Evaporation (mm)

Area	Station	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total	Period
mine	Andasibe (Perinet)	92.7	90.5	99.8	86.0	87.4	73.8	58.3	53.7	53.0	54.6	68.1	98.6	917	1962-1973
	% of annual	10%	10%	11%	9%	10%	8%	6%	6%	6%	6%	7%	11%	100%	

Source: Adapted from Chaperon et al. (1993).

Note: Numbers have been rounded for presentation purposes.

Table 8.1-8 Monthly Piche Evaporation (mm)

Area	Station	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total	Period
tailings, plant, port	Toamasina	76.2	68.8	68.3	55.8	63.8	51.0	50.8	50.2	52.9	55.2	59.3	68.6	720.9	1990-2000
	% of annual	11%	10%	9%	8%	9%	7%	7%	7%	7%	8%	8%	10%	100%	

Source: Madagascar Ministry of Public Works and Transport, Meteorology Branch 2005.

Note: Numbers have been rounded for presentation purposes.

Table 8.1-9 Evapotranspiration Estimates

Area	Description	Potential ET (mm/y)	Actual ET (mm/y)
mine	highlands	1,000	700 - 800
tailings, plant, port	east coast	1,000 - 1,300	1,000 - 1,300

Source: Adapted from Chaperon et al (1993).

2.5.2 Project Regions

The Ambatovy ore body is located along the crest of the Ambavalabe ridge. This ridge is part of the larger Anokay ridge and represents a drainage divide for the

region. The western part of the mine area drains to the Mangoro watershed, while the eastern area is part of the Vohitra and Rianila watersheds.

Near the project area, the Mangoro River flows in a generally southern direction, eventually turning east and discharging into the Indian Ocean near the town of Ambodiharina. The total watershed area of the Mangoro basin is 17,175 square kilometers (km²).

Surface water from the mine area that flows eastward enters tributaries to the Sahatandra River and then the Vohitra River. The Vohitra River flows primarily to the east and joins the Rianila River near the coast of Madagascar. The Rianila River empties into the Indian Ocean near the town of Andevoranto and has a total watershed area of 7,820 km².

These main rivers are relatively large with high average annual flows. The average flow of the Mangoro River is 88.9 m³/s at the Mangoro Gare gauging station as shown in Table 8.1-10. Mangoro Gare is about 20 km south of the project area and the river at this point has a drainage area of 3,600 km². The average flow of the Vohitra River, measured at Andekaleka near the east coast of Madagascar, is 140 m³/s.

The tailings facility, port and plant are located near Toamasina. The main river in the region is the Ivondro River which discharges to the Indian Ocean about 10 km south of the city. At Ringa-Ringa, the Ivondro River has a mean annual flow of 110 m³/s and a drainage area of 2,560 km².

Runoff amounts vary by region and are primarily a function of rainfall (see Table 8.1-11). Annual runoff in the Mangoro basin is roughly 720 mm, while the runoff in the upper Vohitra basin is about 1,100 mm and close to 1,700 mm in the lower (Rianila) watershed. This is due to greater precipitation below the eastern escarpment and at the coast. Runoff coefficients of 0.5 to 0.6 for each basin were derived by Chaperon et al. (1993) based on data from 1949 to 1970.

Extreme daily discharges for these rivers are summarized in Tables 8.1-12 and 8.1-13. The rating curves for these stations are poorly defined for high flows, and result in extrapolated flows for return periods equal to and greater than ten years.

Table 8.1-10 Mean Monthly and Annual Flows of Rivers in the Project Region

River	Drainage Area (km ²)	Period Of Record	Mean Monthly flow (m ³ /s)												Annual
			Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	
Vohitra at Rogez	1,910	1951-1980	41.3	62.1	105	116	132	77.4	54.9	53.2	56.8	58.6	45.8	36.2	69.8
Vohitra at Andekaleka	2,615	1951-1979 (extended)	77.3	127	234	256	274	151	105	97.5	105	110	81.2	66.8	140
Rianila at Brickaville	6,000	1951-1969	222	299	465	508	720	382	291	284	294	279	221	179	345
Rianila at Fetraomby	1,863	1963-1973	85.2	115	245	233	216	146	107	100	104	140	94.4	80.8	139
Mangoro at Mangoro Gare	3,600	1956-1997 ^(b)	52.4	111	165	179	177	109	68	56.6	49.8	42.5	34.2	22.5	88.9
Ivondro at Ringa-Ringa	2,560	1952-1996 ^(a)	67.3	101	148	152	186	129	99.8	93.5	97.5	96.7	80.2	69.2	110

Source: ^(a) Madagascar Ministry of Public Works and Transport, Meteorology Branch 2005 (1984-1996 data).

^(b) Madagascar Ministry of Public Works and Transport, Meteorology Branch 2005 (1979-1997 data).

Note: Numbers have been rounded for presentation purposes.

Table 8.1-11 Basin Runoff Coefficients for Project Area (1949-1970)

River	Drainage Area (km ²)	Precipitation (mm)	Runoff (mm)	Runoff Coefficient
Vohitra at Rogez	1,910	2,199	1,142	0.52
Vohitra at Andekaleka	2,615	2,699	1,507	0.56
Rianila at Brickaville	6,000	2,899	1,720	0.59
Mangoro at Mangoro Gare	3,600	1,482	723	0.49
Ivondro at Ringa-Ringa	2,560	2,501	1,272	0.51

Source: Adapted from Chaperon et al. 1993.

Table 8.1-12 Extreme Daily Discharge for Various Return Periods (m³/s)

River	Drainage Area (km ²)	Period Of Record	Minimum Daily Flow, Qmin (m ³ /s)			Maximum Daily Flow, Qmax (m ³ /s)		
			10 years	5 years	2 years	2 years	5 years	10 years
Vohitra at Rogez	1,910	1951-1980	18.2	20.5	25.3	678	1,690	2,530 ^(a)
Vohitra at Andekaleka	2,615	1951-1979 (extended)	27.6	31.6	41.5	780	NA	3,300 ^(a)
Rianila at Fetraomby	1,863	1963-1973	40.1	44.6	53.8	2220	3,810	4,970 ^(a)
Rianila at Brickaville	6,000	1951-1969	34.5	50.3	88.5	3090	4,900	6,370 ^(a)
Mangoro at Mangoro Gare	3,600	1956-1979	20.2	21.3	23.3	440	810	1,210 ^(a)
Ivondro at Ringa-Ringa	2,560	1952-1983	33.1	36.4	44	865	1,770	2,450 ^(a)

Source: Chaperon et al. 1993.

Notes: ^(a) Extrapolated values.

NA = not available.

Table 8.1-13 Extreme Daily Unit Discharge for Various Return Periods (l/s/km²)

River	Drainage Area (km ²)	Period Of Record	Minimum Daily Flow, qmin (l/s/km ²)			Maximum Daily Flow, qmax (l/s/km ²)		
			10 years	5 years	2 years	2 years	5 years	10 years
Vohitra at Rogez	1,910	1951-1980	9.5	10.7	13.2	355	885	1,325 ^(a)
Vohitra at Andekaleka	2,615	1951-1979 (extended)	10.6	12.1	15.6	300	NA	1,260 ^(a)
Rianila at Fetraomby	6,000	1951-1969	5.8	8.4	14.8	515	815	1,060 ^(a)
Rianila at Brickaville	1,863	1963-1973	21.5	23.9	28.9	1190	2040	2,680 ^(a)
Mangoro at Mangoro Gare	3,600	1956-1979	5.6	5.9	6.5	120	225	340 ^(a)
Ivondro at Ringa-Ringa	2,560	1952-1983	12.9	14.2	17.2	338	690	960 ^(a)

Source: Chaperon et al. 1993.

^(a) Extrapolated values

NA = not available.

3 FIELD PROGRAM RESULTS

The following sections summarize results from the field program including climate characteristics recorded at the mine site and streamflow data collected as part of the hydrometric monitoring program.

3.1 TEMPERATURE

Recorded mean monthly temperatures at the mine site are summarized in Table 8.1-14 for the 1997-2005 period. Based on the available data, the warmest month is February (20.1°C), the coolest is July (13.6°C), and the mean annual temperature is about 17°C.

Table 8.1-14 Mean Monthly Temperatures at Mine Site (°C)

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
1996-1997			19.5	20.4	19.8	18.5	16.8	14.8	13.5	14.4	15.3	15	
1997-1998	19.5	19.6	20.0	21.3	19.8	18			13.1	13.7	15.2	16.5	
1998-1999	17.9	19.6	19.2	20.2									
1999-2000			20.4	18.7	18.3		16.9	14.1	13.4	13.5	14.3	16.3	
2000-2001	17.8	19.3	20.1			18.3	17.4	13.9	13.7	14.4			
2001-2002	18		20.4	19.8	19.4	17.9	16.2	13.8	14.3	13.3	14.9	16.2	
2002-2003	19.5	19.2	19.8	19.9	19.3	18.9	18.2	14.6	12.9	13.1	14.8	17.5	17.3
2003-2004	18.8	19.8	19.9		19.3	18.4	15.7	13.9	14.3		15.9		
2004-2005	17.8			20.6									
Average	18.5	19.5	19.9	20.1	19.3	18.4	16.9	14.2	13.6	13.7	15.1	16.3	17.1

Notes: Based on daily records with up to six days of missing data per month; blanks indicate insufficient daily record to calculate a monthly total (i.e., >six days of missing data).

3.2 RAINFALL

Mean monthly rainfall recorded at the mine site is presented in Table 8.1-15. The wettest months are from December through March with close to 70% of the annual rainfall occurring over this four month period (15 to 19% of the annual rainfall on a monthly basis). The dry season spans April to November with considerably less rainfall (2 to 5% of the annual rainfall on a monthly basis).

The available data suggests that the mean annual rainfall over the period of record is approximately 1,400 mm. The monthly values, however, are in some cases based on incomplete records where daily data are missing for up to six days in the month. No obvious rainfall events were occurring in these cases, however, actual rainfall may be higher than the estimates provided in Table 8.1-15.

Table 8.1-15 Mean Monthly Rainfall at Mine Site (mm)

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
1996-1997			285	184	106	75	60	52	69	48	31	44	
1997-1998	276	86	305	367	53	52			57	73	93	16	
1998-1999	12	251	107	44									
1999-2000			99	440	553		35	102	139	60	22	11	
2000-2001	38	164	476			49	30	49	39	90			
2001-2002	7		135	379	158	91	192	88	50	87	54	17	
2002-2003	34	374	352	116	40	20	70	52	59	35	70	24.4	1,246
2003-2004	51	212	311		337	5	13	8	33		31		
2004-2005	55			239	238								
Mean	68	217	259	253	212	49	67	59	64	66	50	22	1,385
Percentage of Mean Annual	5%	16%	19%	18%	15%	4%	5%	4%	5%	5%	4%	2%	

Note: Based on daily records with up to six days of missing data per month; blanks indicate insufficient daily record to calculate a monthly total (i.e., >six days of missing data).
Numbers have been rounded for presentation purposes.

Maximum daily rainfall amounts (7 AM to 7 AM) for the period of record are summarized in Table 8.1-16. The period of record is incomplete over the December to March wet seasons as indicated by blanks in the table. The maximum daily rainfall recorded at the mine site was 282 mm on March 2, 2000.

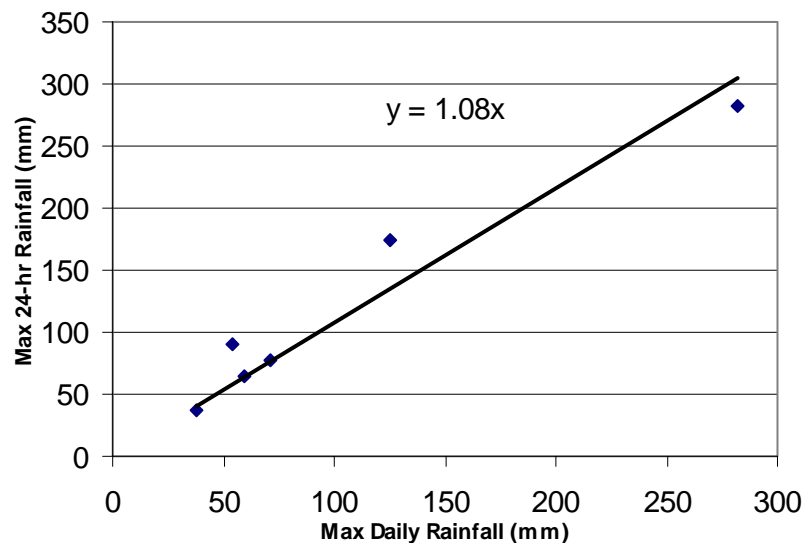
Maximum 24-hour rainfall amounts were also derived from 1-hour rainfall data to compare with maximum daily values. As shown in Figure 8.1-1, maximum 24-hour rainfalls at the mine site are about 1.08 times the recorded daily maximum values.

Table 8.1-16 Maximum Daily Rainfall Recorded at Mine Site (mm)

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
1996-1997			4.4	27.0	26.2	21.6	11.4	7.8	8.2	9.0	7.4	8.0
1997-1998	40.6	21.2	71.4	54.6	13.0	6.2			7.6	6.8	48.2	2.2
1998-1999	2.6	63.4	20.2	55.6		6.6	9.0	3.8				6.3
1999-2000	22.2	65.0	23.1	145.7	282.1		12.9	13.1	33.9	7.8	3.5	3.6
2000-2001	11.8	37.0	72.0			14.2	8.0	6.6	9.2	17.4		
2001-2002	1.6		59.2	87.6	21.6	22.4	60.4	11.2	7.6	8.0	12.6	3.2
2002-2003	8.4	64.4	37.4	15.8	7.8	9.6	50.6	10.4	9.2	4.8	8.0	10.8
2003-2004	17.6	59.0	56.0		124.8	1.4	3.0	2.2	10.0		6.0	
2004-2005	23.2			38.4								

Note: Based on daily records with up to six days of missing data per month; blanks indicate insufficient daily record (i.e., >six days of missing data).

Figure 8.1-1 Comparison of Maximum 24-hour and Daily Rainfall Amounts



3.3 HUMIDITY

Mean monthly relative humidity data at the mine site is given in Table 8.1-17. Little seasonal trend is apparent, however lowest mean values were recorded in October and November.

Table 8.1-17 Mean Monthly Relative Humidity (%)

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
1996-1997			91.1	93.5	90.1	93.0	93.9	94.5	95.0	92.5	91.0	91.3	
1997-1998	89.4	89.7	94.7	95.2	94.2	96.4			97.2	97.3	95.9	92.2	
1998-1999	88.7	93.1	94.5	92.9									
1999-2000			90.0	97.9	97.5		95.3	98.0	98.6	97.3	93.9	92.5	
2000-2001	94.0	95.5	96.3			95.8	93.9	98.5	96.9	97.1			
2001-2002	90.4		91.1	96.5	97.1	97.7	98.6	99.2	96.7	99.1	96.9	95.7	
2002-2003	91.9	96.9	98.4	96.6	97.9	96.4	96.4	97.2	98.7	97.1	96.5	92.0	
2003-2004	92.6	94.9	97.1		97.6	97.3	98.0	98.5	97.6		94.7		
2004-2005	94.6			97.1	97.8								
Mean	91.6	94.0	94.2	95.7	96.0	96.1	96.0	97.7	97.2	96.7	94.8	92.8	95.2

Note: Based on daily records with up to six days of missing data per month; blanks indicate insufficient daily record (i.e., >six days of missing data).

3.4 EVAPOTRANSPIRATION

Potential evapotranspiration is calculated¹ and recorded every hour at the mine site climate station. Results are summarized in Table 8.1-18. The table includes estimated monthly values where up to six days of missing data were filled in based on average daily values. The data suggests that potential evapotranspiration at the mine site ranges from 50 to 120 mm on a monthly basis, and that the annual total is around 1,000 mm.

Table 8.1-18 Mean Monthly Potential Evapotranspiration (mm)

Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
1996-1997		134	127	101	115	88.6	69.9	59.9	54.6	74.1	87.1	92.3	
1997-1998	125	124	106	99	103	68			47	59	75	104	
1998-1999	135	118	116	111		70	64						
1999-2000												96	
2000-2001	101		93			79		45	52	61			
2001-2002	119	103	118	94	91	70	48	46	49	46	69	82	
2002-2003	119	111	97		87	72	62	51					
2003-2004		101	92		78	78	52		50		85		
2004-2005				95									
Mean	120	115	107	100	95	75	59	50	51	60	79	94	1,005

3.5 STREAMFLOW AND RUNOFF

The hydrometric monitoring program involved monthly discharge measurements and daily water level readings at 12 locations in the mine area and four locations near the tailings facility (see Table 8.1-19). Rating curves were developed for each station based on the recorded discharge and water level measurements. The rating curves and daily water level record were then used to derive a hydrograph (time series of flows) from April 2004 through March 2005 at each location. Graphs of the daily flow series are provided in Volume I-8.1 Attachment 1. Daily water level readings are ongoing at all locations.

The mine area stations include four stations located on the relatively small streams that drain the immediate mine area. The Upper Sahamarirana (QESF-100) and Antsahalava (QESF-106) rivers drain the Ambatovy ore body to

¹ Potential evapotranspiration is calculated by the Groweather meteorological station using the Penman equation modified method. The method uses temperature, wind speed, and relative humidity and solar radiation to estimate potential evapotranspiration.

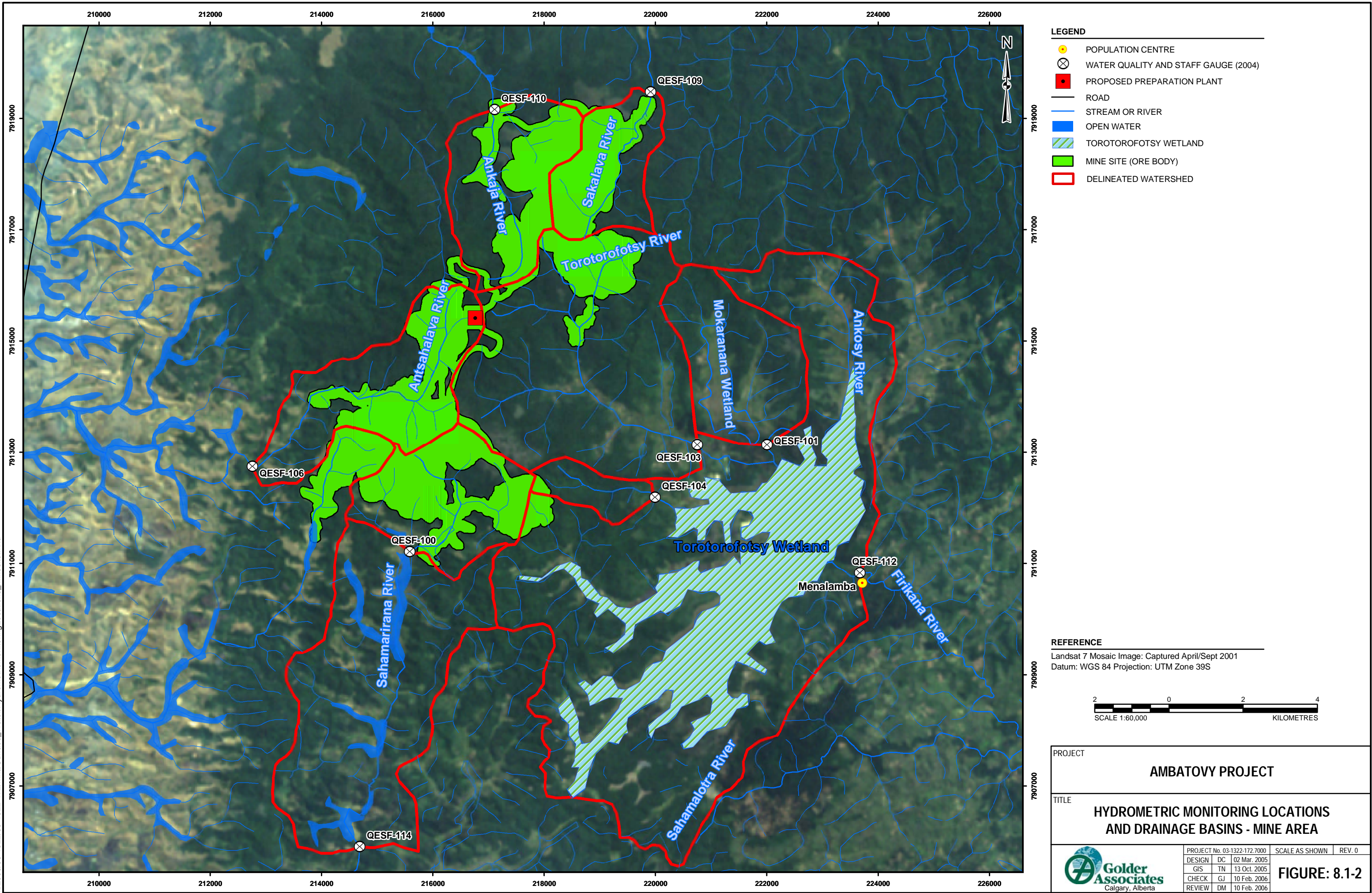
the south and west, respectively, while the Ankaja (QESF-110) and Sakalava (QESF-109) rivers drain the Analamay ore body to the north. There is one station located in the downstream Sahamarirana basin (QESF-114), three stations at the inlet to the Torotorofotsy wetlands (QESF-101, 103 and 104), and one station on the Firikana River at the outlet of the wetlands (QESF-112). The locations and drainage areas associated with these stations are shown in Figure 8.1-2. Three additional stations are located about 20 km to the west of the mine area on the Mangoro River (QESF-120, 121 and 115).

Three stations in the tailings area are located on the Ambolona River as shown in Figure 8.1-3. The stations (QESF-203, 207 and 201) capture flows from three tributaries that flow east to west from the tailings area along distinct valleys toward the coast. A fourth station is located about 10 km to the south on the Ivondro River near the town of Ringa-Ringa (QESF-229).

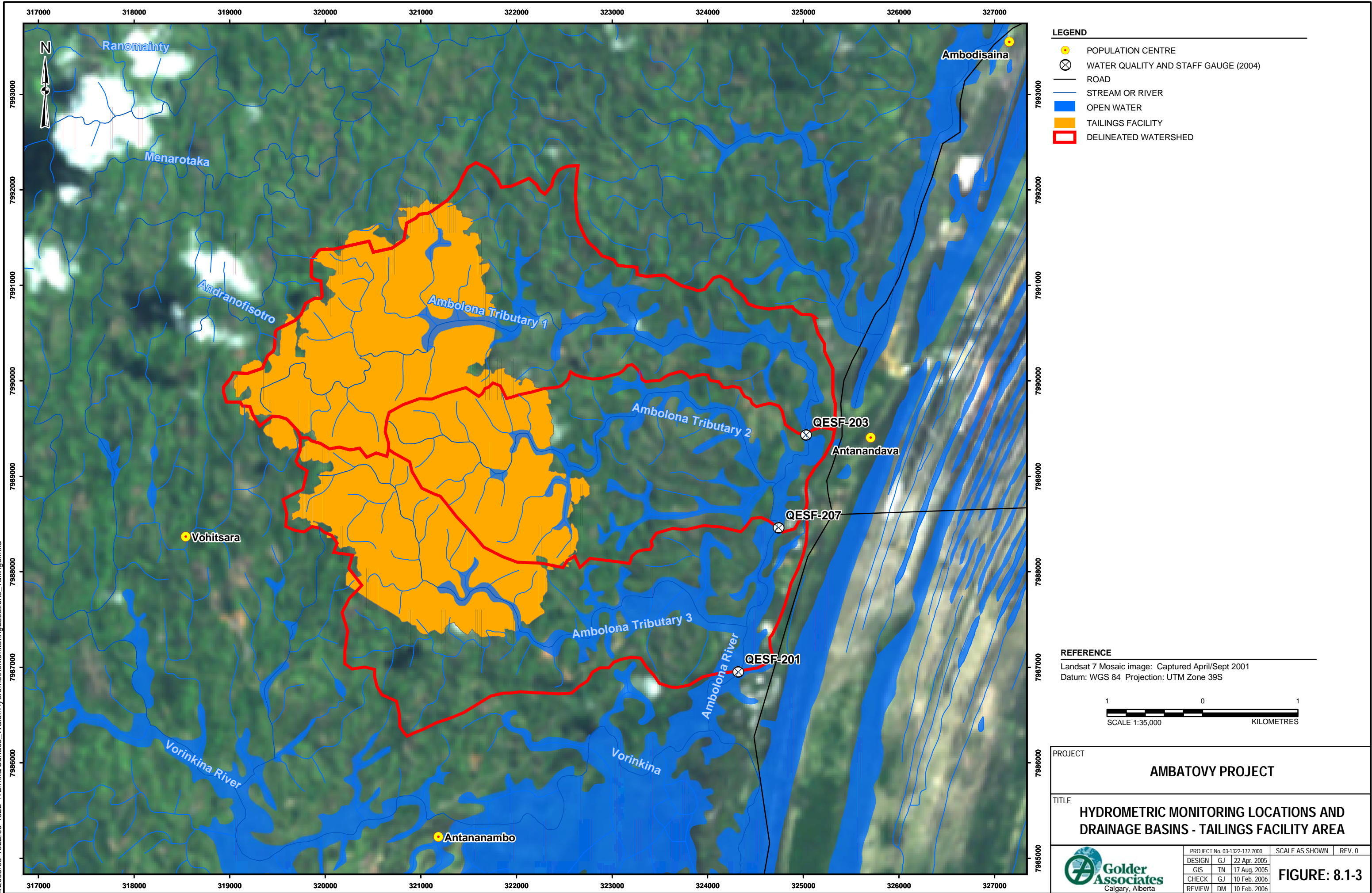
Table 8.1-19 Hydrometric Monitoring Locations

Project Area	Basin	Station	Easting	Northing	Drainage Area (km ²)	Watercourse Name
mine area	Sahamarirana	QESF-100	215583	7911213	5.5	Upper Sahamarirana River
		QESF-114	214686	7905909	19.5	Lower Sahamarirana River
	Antsahalava	QESF-106	212758	7912748	6.8	Antsahalava River
	Ankaja	QESF-110	217109	7919156	5.8	Ankaja River
	Sakalava	QESF-109	219912	7919476	3.7	Sakalava River
	Torotorofotsy	QESF-103	220747	7913139	15.1	Torotorofotsy River (upstream of wetlands)
		QESF-104	219991	7912192	1.9	west tributary to Torotorofotsy wetlands
		QESF-101	222004	7913134	21.1	outlet of Mokaranana wetlands
		QESF-112	223673	7910837	61.2	Firikana River (outlet of Torotorofotsy wetlands)
	Mangoro	QESF-121	194407	7915168	<3,600	Mangoro River upstream of tributary
		QESF-120	194394	7913203	Approx. 3,600	Mangoro River downstream of tributary (about 4 km upstream of QESF-115)
		QESF-115	195841	7910025	3,600	Mangoro River near Village
tailings, plant, port area	Ambolona	QESF-203	325028	7989435	9.4	Ambolona (Tributary 1)
		QESF-207	324742	7988463	16.1	Ambolona (downstream of Tributary 2)
		QESF-201	324319	7986955	24.4	Ambolona (downstream of Tributary 3)
	Ivondro	QESF-229	314909	7988652	2,560	Ivondro River at Ringa-Ringa

I:/2003/03-1322/03-1322-172/mxd/Surface_Water/HydrometricMonitoringLocations_Minesite.mxd



i:/2003/03-1322/03-1322-172/mxd/Surface_Water/HydrometricMonitoringLocations_Tailings.mxd



3.5.1 Monthly and Annual Flows and Runoff

The available hydrographs (Volume I-8.1, Attachment 1) show two distinct seasons: the dry season between April and November, and the wet season between December and March. Low flows over the dry season decreased steadily between April and mid-December 2004. A rapid increase in flows occurred toward the end of December and beginning of January, presumably as a result of high rainfall and the start of the rainy season. Water levels and flows remained elevated through January and February, and rose again rapidly in early March 2005. The streams returned to pre-peak conditions within a few days, with a return to low flow conditions by the beginning of April 2005.

Mean monthly and annual flows were derived from the hydrographs and are summarized in Table 8.1-20. The equivalent runoff amounts are provided in Table 8.1-21.

As shown in Table 8.1-22, depending on location, the minimum monthly flows occurred in either October or November, and the maximum monthly flows occurred in either January or March. For smaller basins, the maximum flows are associated with heavy rainfall events, and therefore the timing of the maximum monthly flow depends on the timing of rainfall activity within the basin. In the larger basins (Mangoro and Ivondro), maximum monthly flows occur toward the end of the wet season when the full drainage basin is contributing to flows.

Annual runoff (stream discharge per unit area) was calculated for each of the monitored basins over the April 2004 to March 2005 period. Basin runoff is commonly used to compare hydrologic response between basins, as flow volumes are normalized over drainage areas. The calculated runoff in the mine area ranged from 427 to 593 mm, with a slightly higher runoff of 613 mm in the Torotorofotsy River drainage. The runoff of 227 mm at QESF-104 is considered unrealistically low compared to the other results. The cause of this discrepancy is not clear, but may be attributed to measurement inaccuracies at low flows and/or an unrepresentative drainage area delineated from available mapping.

Runoff estimates for the Mangoro basin range from 625 to 899 mm at QESF-120 and QESF-115, respectively. The runoff amounts at these locations are expected to be similar due to the similar drainage basin sizes. The discrepancy between the estimates can be attributed in part to extrapolation of the available rating curves to derive high flows at high water levels over the December to March period.

Table 8.1-20 Derived Monthly Discharges at Hydrometric Monitoring Locations

Project Area	Station QESF	Watercourse	Drainage Area (km ²)	Mean Monthly Discharge (m ³ /s)												Annual
				2004									2005			
				Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	
mine area	100	Upper Sahamarirana River	5.5	0.17	0.12	0.10	0.09	0.07	0.06	0.06	0.06	0.06	0.13	0.15	0.19	0.11
	114	Lower Sahamarirana River	19.5	0.23	0.19	0.22	0.18	0.15	0.12	0.11	0.11	0.51	0.69	0.56	0.75	0.32
	106	Antsahalava River	6.8	0.12	0.10	0.10	0.09	0.08	0.08	0.07	0.07	0.08	0.12	0.12	0.17	0.10
	110	Ankaja River	5.8	0.10	0.08	0.07	0.06	0.06	0.05	0.05	0.05	0.07	0.13	0.14	0.39	0.10
	109	Sakalava River	3.7	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.02	0.10	0.12	0.22	0.05
	103	Torotorofotsy River	15.1	0.23	0.21	0.18	0.15	0.13	0.12	0.10	0.10	0.99	0.67	0.31	0.36	0.30
	104	west tributary to Torotorofotsy Wetlands	1.6	0.003	0.004	0.007	0.006	0.005	0.004	0.003	0.003	0.007	0.055	0.038	0.040	0.014
	101	outlet of Mokaranana Wetlands	5.5	0.06	0.07	0.04	0.04	0.03	0.02	0.02	0.00	0.18	0.20	0.21	0.17	0.09
	112	Firikana River (outlet of Torotorofotsy Wetlands)	61.2	0.75	0.57	0.74	0.53	0.36	0.31	0.20	0.16	2.57	2.73	2.24	2.90	1.17
	121	Mangoro River upstream of Tributary	Approx. 3,600	53.3	48.2	44.4	42.4	39.1	36.3	31.0	32.2	64.7	93.8 ^(b)	118 ^(b)	111 ^(b)	59.6
	120	Mangoro River downstream of Tributary	Approx. 3,600	71.6	60.7	52.6	46.8	39.1	32.8	21.8	23.5	83.8	126 ^(b)	146 ^(b)	171 ^(b)	73.1
	115	Mangoro River near village	3,600	88.4	67.7	56.7	49.5	38.6	30.9	20.5	22.6	140	216 ^(c)	272 ^(c)	357 ^(c)	113
tailings area	203	Ambolona (Tributary 1)	9.4	0.51	0.46	0.47	0.42	0.37	0.35	0.29	0.14	0.27	0.32	0.22	0.31 ^(a)	0.34
	207	Ambolona (downstream of Tributary 2)	16.1	1.34	0.95	1.09	0.76	0.41	0.22	0.10	0.08	1.07	1.26	0.71	0.99 ^(a)	0.75
	201	Ambolona (downstream of Tributary 3)	24.4	2.19	1.33	1.65	0.97	0.78	0.66	0.53	0.52	2.49	2.14	1.30	1.82 ^(a)	1.36
	229	Ivondro River at Ringa-Ringa	2,560	n/a	n/a	n/a	90.9	75.7	61.3	50.2	43.6	180	173	136	191 ^(a)	n/a

(a) Estimated as 1.4 times the flow in February, based on data from mine area.

(b) Extrapolated from daily values above 100 m³/s

(c) Extrapolated from daily values above 200 m³/s.

n/a = Not available.

Note: Flows at QESF-120 and QESF-115 are expected to be similar in magnitude due to their similar drainage area; the discrepancies noted between flows in January through March are presumably a result of extrapolation of the rating curves at high water levels.

Table 8.1-21 Derived Monthly Runoff at Hydrometric Monitoring Locations

Project Area	Station QESF	Watercourse	Drainage Area (km ²)	Mean Monthly Runoff (mm)												Annual
				2004									2005			
				Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	
mine area	100	Upper Sahamarirana River	5.5	81	57	45	41	36	30	29	28	31	63	68	84	593
	114	Lower Sahamarirana River	19.5	31	26	30	24	21	16	16	15	71	94	70	93	505
	106	Antsahalava River	6.8	45	40	36	35	31	29	29	28	31	49	43	59	454
	110	Ankaja River	5.8	45	35	31	29	27	23	23	24	32	59	59	161	546
	109	Sakalava River	3.7	27	22	20	17	12	8	7	6	13	75	78	145	427
	103	Torotorofotsy River	15.1	40	37	31	27	24	20	18	16	176	118	50	57	613
	104	West Tributary to Torotorofotsy Wetlands	1.6	5	7	12	9	8	6	5	4	12	92	57	60	277
	101	outlet of Mokaranana Wetlands	5.5	30	31	21	17	13	8	7	2	86	96	91	77	478
	112	Firikana River (outlet of Torotorofotsy Wetlands)	61.2	32	25	31	23	16	13	9	7	113	119	89	115	591
	121	Mangoro River upstream of tributary	3,000 ^b	46	43	38	38	35	31	28	28	58	84	95	90	614 ^(b)
	120	Mangoro River downstream of tributary	3,600	52	45	38	35	29	24	16	17	62	94	98	115	625
115	Mangoro River near village	3,600	64	50	41	37	29	22	15	16	104	161	183	240	899	
tailings area	203	Ambolona (Tributary 1)	9.4	140	130	128	119	107	97	82	39	77	90	57	89 ^(a)	1,155
	207	Ambolona (downstream of Tributary 2)	16.1	216	157	176	126	69	35	17	13	178	210	106	165 ^(a)	1,468
	201	Ambolona (downstream of Tributary 3)	24.4	232	146	175	107	86	70	58	55	273	235	129	200 ^(a)	1,765
	229	Ivondro River at Ringa-Ringa	2,560	n/a	n/a	n/a	95	79	62	53	44	188	181	129	199 ^(a)	n/a

^(a) Estimated as 1.4 times the flow in February, based on recorded flows from mine area.

^(b) Runoff amounts based on estimated drainage area (assumes the tributary drainage area between QESF-121 and QESF-120 is approximately 600 km²).

n/a = Not available.

Notes: The derived annual runoff for QESF-104 is considered unrealistically low compared to other stations; the cause of this is unclear but could be associated with inaccurate hydrography and delineated drainage area and/or inaccuracies with measuring very low flows.

Numbers have been rounded for presentation purposes.

Table 8.1-22 Month of Minimum and Maximum Mean Monthly Flow

Project Area	Sub-Area	Mean Monthly Flow 2004-2005 (month)	
		Minimum	Maximum
mine area	mine	October	March
	Torotorofotsy	November	January
	Mangoro	October	March
tailings, plant and port areas	Tailings	November	January
	Ivondro	November	March

Annual runoff in the tailings area is considerably higher than in the mine area. The available data suggest an annual runoff between 1,200 and 1,800 mm for the main stem of the Ambolona river which receives tributary inflows from the tailings valleys.

3.5.2 Daily Peak and Low Flows

Tables 8.1-23 and 8.1-24 summarize the peak and low flows recorded during the 2004-2005 monitoring program for the mine site. Comments on the flow characteristics in each area are summarized in the following bullets:

3.5.2.1 Mine Area

- Peak runoff in the mine site area varies from a low of 0.97 l/s/km² at QESF-101 to a high of 349 l/s/km² at QESF-109. Differences between peak flow estimates should be viewed with caution, however, since all peak flows were estimated using extrapolations of their respective stage-discharge curves.
- The peak flow response of the stations north of Analamay (QESF-109 and QESF-110) are similar, with a maximum recorded flow at QESF-109 of 349 l/s/km².
- Low flows at QESF-109 and QESF-110 differed markedly. The QESF-109 watershed appears to have minimal storage and perhaps receives only small amounts of groundwater recharge. These characteristics are consistent with the highly variable dry season flows, and the lowest dry season runoff of the stations to the west, north and south of the mine. The lowest recorded flow at QESF-109 was 1.9 l/s/km², while the minimum recorded flows at QESF-110 was 6.9 l/s/km².
- The responses of stations QESF-100 (immediately south of Ambatovy) and QESF-106 (immediately west of Ambatovy) were very similar. Dry

season flows at the two stations were comparable to QESF-110 (northwest of Anamalay), with very stable flow near 10 l/s/km^2 , suggesting significant groundwater contributions. QESF-100 and QESF-106 appear to have more storage in their watersheds, as day-to-day variability and peak flows are lower than at the other stations.

- QESF-114 (the lower Sahamarirana, south of Ambatovy) exhibits similar peak flow responses to QESF-109 and QESF-110, with maximum recorded flows of 240 l/s/km^2 . Somewhat surprisingly, the variability of flows and peak runoff at this station are much greater than at QESF-100 located about 5 km upstream. Dry season runoff is lower than at QESF-100, likely because groundwater contributions are a larger percentage of total dry season flows in the upper watershed than in the lower.

3.5.2.2 Mine Area (Torotorofotsy Sub-Area)

- Peak runoff during the wet season was comparable at all Torotorofotsy area gauging stations.
- Outflows from the Torotorofotsy wetlands (QESF-112, the Firikana River) were more variable than either of the two measured inflows. This result was unexpected since a wetland typically reduces the variability in flows, resulting in lower peaks, higher dry season discharges, and less day-to-day fluctuation. However, the Torotorofotsy wetlands have been channelized in many locations, which may be the source of the unusual flow variability.
- Flows in the Torotorofotsy River (QESF-103), the main tributary to the Torotorofotsy wetlands, were highly attenuated, with a relatively high base flow of about 10 l/s/km^2 . This is consistent with other stations with significant groundwater inflows, and with the hydrogeologic analysis, which shows this watershed to be strongly influenced by groundwater flow (see Volume I, Section I-7.1).
- Dry season flows from the Mokaranana wetlands (QESF-101) were lower than at all other stations, reaching a minimum of 0.42 l/s/km^2 , the lowest of all mine area stations. The very low dry season runoff at the station is consistent with the groundwater analysis, which suggests that only a small portion of the watershed receives recharge from the adjacent Ambavalabe ridge (see Volume I, section I-7.1).

3.5.2.3 Mine Area (Mangoro River)

- Mangoro River flows upstream and downstream of a major unnamed tributary (QESF-121 and QESF-120) were similar during the dry season, with low flows on the order of 20 to $80 \text{ m}^3/\text{s}$. The contribution from the unnamed tributary was minimal over this period.

- During the wet season, the flow contribution from the unnamed tributary was more pronounced, resulting in peak flows at QESF-121 of 55 l/s/km² and at QESF-120 of 69 l/s/km².
- Mangoro River flows near the Village (QESF-115) were comparable to the two upstream stations over the dry season. The station is located about 5 km downstream of QESF-120 and there are no major tributaries along this reach.
- Although expected to be similar, the high flows during the wet season were markedly different at QESF-115 and QESF-121. Peak flow estimates derived by extrapolating the available rating curves were 201 l/s/km² and 55 l/s/km² for QESF-115 and QESF-121, respectively. The differences are likely due primarily to extrapolation of the rating curves.

3.5.2.4 Tailings Area

- The lower portions of the Ambolona watershed (QESF-207 mid-basin and QESF-201 lower basin) exhibit very similar runoff responses to rainfall. The unit discharges at these locations are essentially the same from April to August and December to March. Unexpectedly lower unit discharges were observed at QESF-207 between September and November. These are inconsistent with measured flows at upstream station QESF-203 and downstream station QESF-201, but may be attributed to a diversion or other abstractions.
- A dampened rainfall response was observed at QESF-203 compared to the lower basin; unit discharges were also noticeably lower during the wet season and early dry season, then slightly higher in the late dry season. This suggests more storage in the upper basin compared to the lower portions.
- Peak flows at QESF-203 (upper), QESF-207 (mid), and QESF-201 (lower) were 104 l/s/km², 397 l/s/km² and 425 l/s/km², respectively.

3.5.2.5 Tailings Area (Ivondro River)

- The daily water level record and estimated flows at the Ivondro River at Ringa-Ringa are limited to August through mid-February.
- A low flow of 14 l/s/km² occurred in late November. Peak flows of about 695 l/s/km² were estimated by extrapolation of the rating curve for high water levels in late December.
- Unit discharge for the Ivondro River in the dry season is about double that recorded in the Mangoro basin, and reflects the higher rainfall on the east coast of the island.
- Extrapolated discharges during the wet season are of comparable magnitude between the Ivondro and Mangoro basins.

Table 8.1-23 Extreme Daily Flows and Water Levels (2004-2005)

Project Area	Station QESF	Watercourse	Drainage Area (km ²)	Minimum Daily Flow			Maximum Daily Flow			Maximum Water Level Difference (m)	Maximum Flow for Rating Curve ^(a) (m ³ /s)
				Date	Water Level (m)	Flow (m ³ /s)	Date	Water Level (m)	Flow (m ³ /s)		
Mine Area	100	Upper Sahamarirana River	5.5	30-Nov-04	0.27	0.03	8-Jan-05	0.90	0.35	0.63	0.19
	114	Lower Sahamarirana River	19.5	27-Nov-04	0.71	0.09	8-Jan-05	2.13	4.69	1.42	0.75
	106	Antsahalava River	6.8	27-Nov-04	0.43	0.07	8-Jan-05	0.82	0.46	0.39	0.16
	110	Ankaja River	5.8	27-Nov-04	0.175	0.04	2-Mar-05	0.50	1.23	0.33	0.43
	109	Sakalava River	3.7	27-Nov-04	0.43	0.007	2-Mar-05	0.97	1.29	0.54	0.36
	103	Torotorofotsy River	15.1	5-Dec-04	0.55	0.07	18-Dec-04	1.20	3.06	0.65	0.36
	104	West Tributary to Torotorofotsy Wetlands	1.6	11-Dec-04	0.42	0.002	11-Jan-05	0.67	0.20	0.25	0.06
	101	Outlet of Mokaranana Wetlands	5.5	22-Nov-04	0.17	0.005	19-Dec-04	0.92	0.51	0.75	0.36
	112	Firikana River (Outlet of Torotorofotsy Wetlands)	61.2	12-Dec-04	0.19	0.09	20-Dec-04	1.69	12.50	1.50	3.79
	121	Mangoro River upstream of tributary	3,000 ^(b)	13-Dec-04	0.64	27.8	21-Dec-04	4.91	165	4.27	107
	120	Mangoro River downstream of tributary	Approx. 3,600	14-Dec-04	0	15.6	22-Dec-04	3.59	247	3.59	96.4
Tailings Area	115	Mangoro River near Village	3,600	15-Dec-04	0.74	12.5	23-Dec-04	3.76	724	3.02	170
	203	Ambolona (Tributary 1)	9.4	28-Nov-04	0.01	0.02	19-Apr-04	0.86	0.98	0.85	0.78
	207	Ambolona (downstream of Tributary 2)	16.1	30-Nov-04	0.18	0.03	19-Apr-04	1.67	6.39	1.49	1.92
	201	Ambolona (downstream of Tributary 3)	24.4	11-Dec-04	0.72	0.35	30-Dec-04	2.50	10.38	1.78	3.44
	229	Ivondro River at Ringa-Ringa	2,560	29-Nov-04	0.97	35.8	28-Dec-04	6.91	1780	5.94	125

^(a) Maximum measured flow used for deriving rating curve (extrapolation above this flow).

^(b) Drainage area estimated as 3,000 km².

Table 8.1-24 Extreme Daily Flows and Unit Daily Flows (2004-2005)

Project Area	Station QESF	Watercourse	Drainage Area (km ²)	Daily Flows (m ³ /s)		Daily Flows (l/s/km ²)		Maximum Water Level Difference (m)	Maximum Flow for Rating Curve ^(a) (m ³ /s)
				Minimum	Maximum	Minimum	Maximum		
Mine Area	100	Upper Sahamarirana River	5.5	0.03	0.35	5.45	63.6	0.62	0.19
	114	Lower Sahamarirana River	19.5	0.09	4.69	4.62	241	1.42	0.75
	106	Antsahalava River	6.8	0.07	0.46	10.29	67.6	0.39	0.16
	110	Ankaja River	5.8	0.04	1.23	6.90	212	0.33	0.43
	109	Sakalava River	3.7	0.007	1.29	1.92	349	0.55	0.36
	103	Torotorofotsy River	15.1	0.07	3.06	4.64	203	0.65	0.36
	104	West Tributary to Torotorofotsy Wetlands	1.6	0.002	0.20	1.24	125	0.25	0.06
	101	Outlet of Mokaranana Wetlands	5.5	0.005	0.51	0.97	92.7	0.75	0.36
	112	Firikana River (Outlet of Torotorofotsy Wetlands)	61.2	0.09	12.50	1.47	204	1.51	3.79
	121	Mangoro River upstream of tributary	3,000 ^b	27.8	165	9.27	55.0	4.27	107
	120	Mangoro River downstream of tributary	Approx. 3,600	15.6	247	4.33	68.6	3.59	96.4
Tailings Area	115	Mangoro River near Village	3,600	12.5	724	3.47	201	3.02	170.4
	203	Ambolona (Tributary 1)	9.4	0.02	0.98	2.13	104	0.85	0.78
	207	Ambolona (downstream of Tributary 2)	16.1	0.03	6.39	1.86	397	1.49	1.92
	201	Ambolona (downstream of Tributary 3)	24.4	0.35	10.38	14.34	425	1.78	3.44
	229	Ivondro River at Ringa-Ringa	2,560	35.8	1,780	13.98	695	5.94	125

^(a) Maximum measured flow used for deriving rating curve (extrapolation above this flow).

3.6 PIPELINE WATER CROSSINGS

Discharge measurements were taken during the 2004-2005 dry season at 12 watercourse crossing locations along the pipeline route. The surveys involved an evaluation of fish resources (see Volume J Section 3.1) and included discharge measurements and characterization of channel morphology. Three of 15 crossings visited could not have valid discharge measurement taken owing to local access difficulties.

A summary of the discharge measurements is provided in Table 8.1-25. Additional morphologic characterization is provided in Volume J Section 3.1.

Table 8.1-25 Reach Characteristics and Discharges Along the Pipeline Route (m³/s)

Pipeline Kilometre Post	Stream Name	Drainage Area (km ²)	Date	Wetted Width ^(a) (m)	Discharge (m ³ /s)
003+500	Vondronina (upper reaches of the Torotorofotsy River)	4.7	Sep. 30, 2004	3.5	0.58
007+500	Unnamed	~1	Oct. 18, 2004	1.2	.04
019+400	Sahatany (Tributary to Sahatandra)	38	Oct. 03, 2004	7.2	1.10
042+500 ^(b)	Volove	28	Oct. 19, 2004	15.0	1.14
107+000	Rianila (Tributary to Vohitra)	~1,860	Sep. 25, 2004	126	57.4
136+000	Sahanavo	n/a	Sep. 22, 2004	77.0	18.4
146+000	Morongolo	~1,000	Oct. 16, 2004	51.4	9.81
157+700	Berohondry	n/a	Oct. 12, 2004	3.2	0.08
175+300	Sandranentana (Tributary to Fanandrana)	n/a	Oct. 13, 2004	3.0	0.08
179+300	Ivondro	~2,560	Oct. 14, 2004	183	50.0
E3 007+000 ^{(c)(d)}	Vohimana	6.5	Sep. 30, 2004	5.45	0.22
E3 011+950 ^(d)	Sahatandra	~7	Oct. 01, 2004	26.5	9.66

^(a) Wetted width at discharge measurement location.

^(b) Recorded as 041+600 (same river within 1 km).

^(c) Recorded as E3 005+150.

^(d) Alternate watercourse crossing location.

n/a = Not available.

~ = Indicates approximate drainage area.

4 SUMMARY OF PROJECT AREA CLIMATE AND HYDROLOGY

4.1 TEMPERATURE

4.1.1 General

Temperatures at the mine site are slightly cooler than at Moramanga and Andasibe (Perinet). The mean annual temperature at the mine site is about 17.1°C based on the available records from 1997-2005. Mean annual temperatures for the available periods of record at Moramanga and Andasibe (Perinet) are 19.6°C (1951-1980) and 19.2°C (1963-1973), respectively.

Temperatures at the tailings area on the coast are considerably warmer than at the mine site. The long-term mean annual temperature is 24.6°C based on data from nearby Toamasina (1950-2004). A summary of mean monthly temperatures is provided in Section 2.1.

The approximately 195-km slurry pipeline runs between the ore preparation plant at the mine and the process plant at the coast. The first 30 km of the pipeline descends from the highlands to the coastal plain, with mean annual temperatures along this section increasing from about 17 to 22°C. The remaining length of pipeline runs from the base of the escarpment, across the coastal plain, to the plant where mean annual temperatures reach upward of 24°C.

4.1.2 2004-2005 Conditions

Data from the mine site indicates that temperatures over the April 2004 to March 2005 period were typical of mean temperatures as characterized by the short period of record. There is no concurrent temperature data available from Moramanga or Andasibe (Perinet) for comparison.

As shown in Table 8.1-26, temperatures at Toamasina were slightly cooler than average for most of 2004 and warmer than average in the first three months of 2005.

Table 8.1-26 Comparison of 2004-2005 and Average Temperatures at Tailings Area (°C)

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
2004-2005	25.5	23.3	21.9	21.5	21.8	22.4	23.4	24.5	25.8	27.1	27.8	27.2
long-term ^(a)	25.8	24.9	23.2	21.7	21.7	22.3	23.6	25.1	26.3	27.0	27.1	26.7
difference	-0.3	-1.6	-1.3	-0.2	+0.1	+0.1	-0.2	-0.6	-0.5	+0.1	+0.7	+0.5

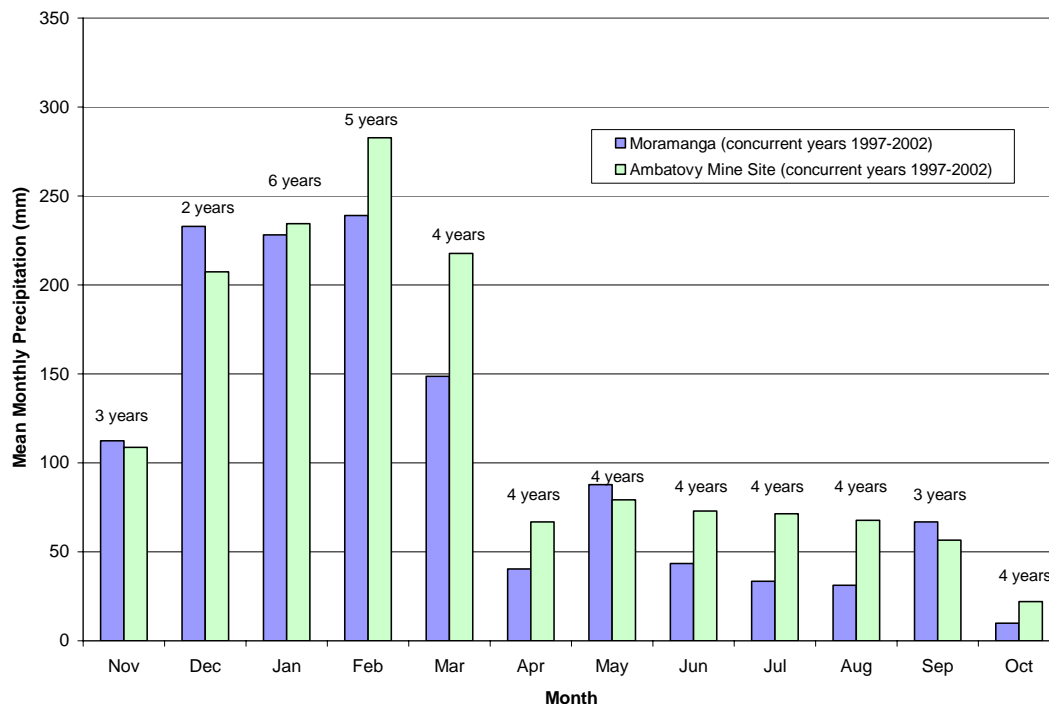
^(a) Period of record 1950-2004.

4.2 RAINFALL

4.2.1 General

There is a five-year concurrent period of record (1997 to 2002) for rainfall data at the mine site and at Moramanga. Figure 8.1-4 shows a comparison of the mean monthly rainfalls and indicates the number of years of data used in the comparison. The pairs of monthly data were used to estimate mean annual rainfalls at the two locations for the concurrent period. Results of the analysis indicate that the mine site receives about 17% more rain than Moramanga on an annual basis. A similar analysis between Andasibe (Perinet) and Moramanga for the 1963 to 1972 concurrent period indicates that Andasibe (Perinet) is about 20% wetter than Moramanga.

Figure 8.1-4 Comparison of Monthly Precipitation at Moramanga and Mine Site



Based on similarities in terms of annual rainfall, rainfall data from Andasibe (Perinet) may be more applicable to the mine site than data from Moramanga. The period of record at Moramanga, however, is considerably longer than that of Andasibe (Perinet) and was therefore used to derive annual and monthly statistics for the mine site. The mean annual rainfall at the mine is estimated to be 1,700 mm, which is calculated from the mean annual rainfall of 1,468 mm at Moramanga and adjusted by 17% to reflect the wetter conditions at the mine site. The mine is slightly drier than Andasibe (Perinet), which has a mean annual rainfall of 1947 mm.

Monthly rainfall amounts at the mine site were derived from the annual total of 1,700 mm and the percent contributions of each month to this total. The monthly percentages were derived as an average of the percentages associated with records at Moramanga and Andasibe (Perinet), and are consistent with percentages derived for the mine site based on its shorter period of record.

The 1,700 mm annual rainfall amount estimated for the mine site is greater than the 1,385 mm estimated from the limited 1997-2005 records. This may be attributed in part to incomplete rainfall records at the mine, the short period of record, and the overall drier conditions between 1997 and 2002 as compared to long-term conditions. Figure 8.1-5 shows that mean monthly rainfalls based on 1997-2002 data are considerably drier than monthly values derived from the 1928-2002 long-term record.

Long-term precipitation for the tailings, plant and port areas is assumed to be equivalent to that of Toamasina. The derived monthly precipitation amounts are summarized in Table 8.1-27 and are shown in Figure 8.1-6.

Mean annual precipitation along the pipeline route was estimated from isohyets provided in Chaperon et al. (1993). The variation in precipitation is shown in Figure 8.1-7.

Figure 8.1-5 Comparison of Monthly Precipitation at Moramanga 1997-2002 and 1928-2002

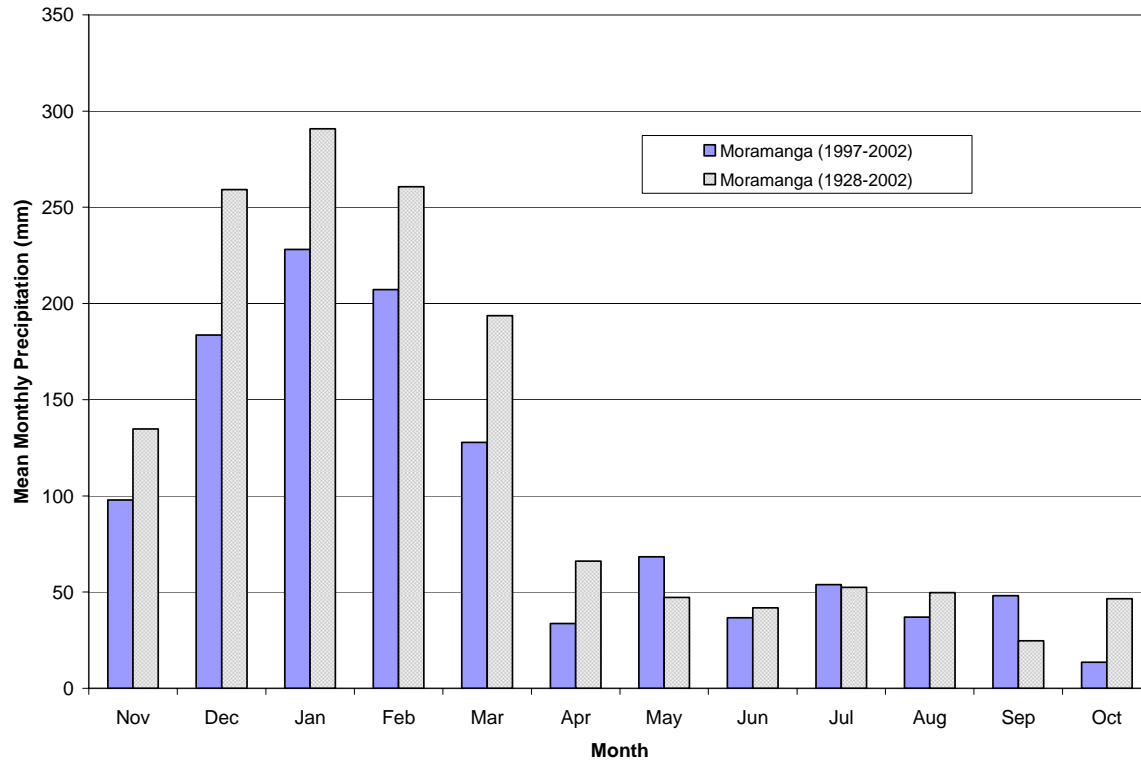


Table 8.1-27 Derived Monthly and Annual Precipitation (mm) for the Project Areas

Area	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
mine ^(a)	139	275	338	273	226	84	53	57	86	80	36	56	1,700
tailings ^(b)	153	307	398	420	473	311	268	260	272	197	126	115	3,300

^(a) Based on a mean annual rainfall of 1,700 mm and percentage contributions of each month to the annual total.

^(b) Mean annual rainfall approximated as 3,300 mm based on long-term monthly precipitation at Toamasina of 3,343 mm. Numbers have been rounded for presentation purposes.

Figure 8.1-6 Derived Monthly Precipitation for the Mine Site and Tailings Area

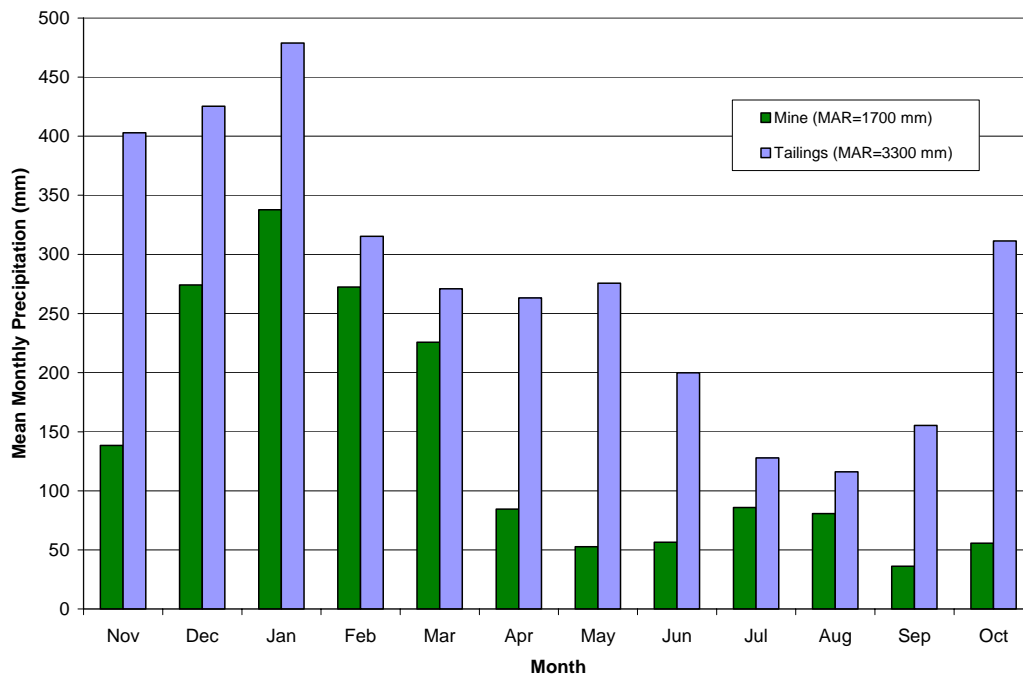
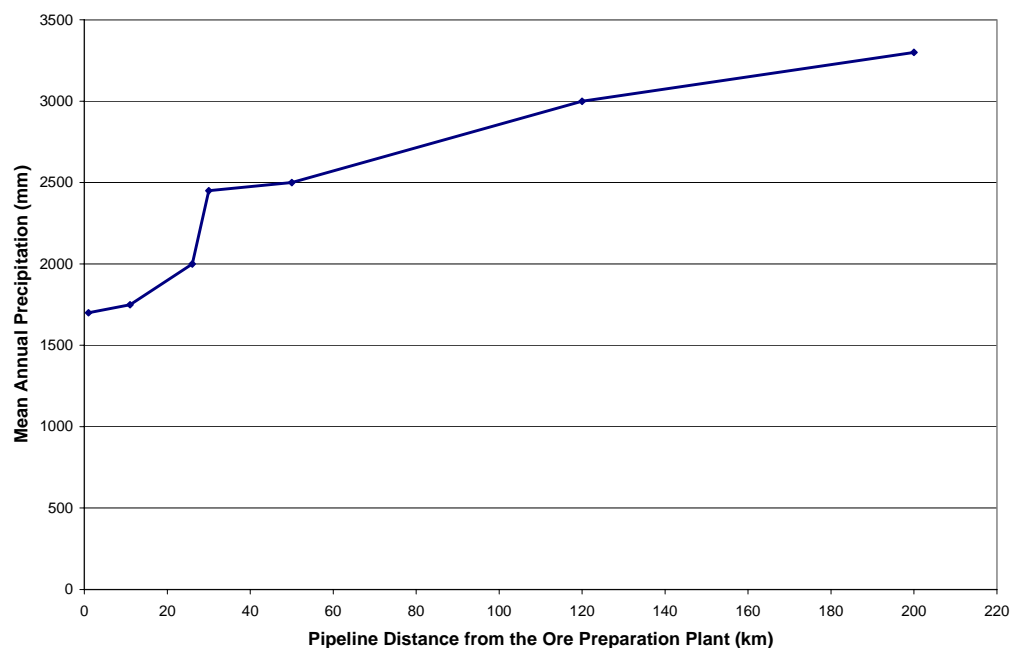


Figure 8.1-7 Derived Mean Annual Precipitation Along the Pipeline Route



Maximum daily rainfall for various return periods are shown in Table 8.1-28 for the mine and tailings areas. Maximum daily rainfall amounts at the mine site are based on data from Andasibe (Perinet) to reflect the higher rainfall conditions at the mine relative to Moramanga. Maximum 24-hour rainfall amounts and intensities (Table 8.1-29a and 8.1-29b) have been estimated by applying a factor of 1.08 to the daily maximum values. This factor was derived based on the short-term data available from the mine site, and was also applied to Toamasina data to derive maximum 24-hour rainfalls in the tailings area.

Site-specific rainfall data have not been analyzed to determine maximum 24-hour rainfall events along the pipeline corridor. It is expected, however, that rainfall intensities will be similar to those at the mine or tailings facility, depending on location and the amount of rainfall characteristic of the area. Maximum rainfall data derived for the tailings area is assumed to be applicable to the majority of the pipeline length as it crosses the coastal plain. For the first 30 km of the pipeline route, however, maximum rainfall amounts will vary from those derived for the mine site to those derived for the coast. Maximum 24-hour rainfall amounts can be estimated by interpolating between the mine and tailings amounts based on the mean annual rainfalls at the sites.

Table 8.1-28 Maximum Daily Rainfall

Area	Maximum Daily Rainfall (mm) for Various Return Periods					
	2-yr	5-yr	10-yr	20-yr	50-yr	100-yr
mine ^(a)	113	168	214	266	346	419
plant ^(b)	159	224	273	326	402	465

^(a) Andasibe (Perinet) rainfall data 1963-1973.

^(b) Toamasina rainfall data 1948-2004.

Table 8.1-29a Maximum 24-hour Rainfall Amount

Area	Maximum 24-hour Rainfall (mm) for Various Return Periods					
	2-yr	5-yr	10-y	20-yr	50-yr	100-yr
mine ^(a)	122	181	231	287	374	453
plant ^(a)	172	242	295	352	434	502
pipeline km 0-30 ^(b)	122-172	181-242	231-295	287-352	374-434	453-502
pipeline km 30-200 ^(c)	172	242	295	352	434	502

^(a) Maximum daily precipitation at Andasibe (Perinet) (Mine) and Toamasina (tailings) adjusted by a factor of 1.08 to convert to maximum 24-hour values.

^(b) Interpolate between mine and tailings rainfall amounts based on differences in annual precipitation.

^(c) Assumed to be equal to conditions at the tailings area.

Table 8.1-29b Maximum 24-hour Rainfall Intensity

Area	Maximum 24-hour Rainfall Intensity (mm/hr) for Various Return Periods					
	2-yr	5-yr	10-yr	20-yr	50-yr	100-yr
mine ^(a)	5.1	7.5	9.6	12.0	15.6	18.9
plant ^(a)	7.2	10.1	12.3	14.7	18.1	20.9
pipeline km 0-30 ^(b)	5.1-7.2	7.5-10.1	9.6-12.3	12.0-14.7	15.6-18.1	18.9-20.9
pipeline km 30-200 ^(c)	7.2	10.1	12.3	14.7	18.1	20.9

^(a) Maximum daily precipitation at Andasibe (Perinet) (Mine) and Toamasina (plants) adjusted by a factor of 1.08 to convert to maximum 24-hour values.

^(b) Interpolate between mine and plants rainfall amounts based on differences in annual precipitation.

^(c) Assumed to be equal to conditions at the plants area.

4.2.2 2004-2005 Conditions

Available mean monthly precipitation at the mine site for the 2004-2005 monitoring period is compared to average amounts in Tables 8.1-30 and 8.1-31. Conditions at the mine site from April to November 2004 were very dry compared to the available mean values derived from incomplete records from 1997 to 2005. The April, June and November totals do not account for up to six days of missing data. There were no obvious rainfall events occurring at those times; however, rainfall totals may in fact be higher than reported in Table 8.1-30. There is no rainfall data available at Moramanga or Andasibe (Perinet) for the 2004-2005 period for further comparison.

Total precipitation in the plant and tailings area from April 2004 to March 2005 was comparable to the long-term average for the area. Monthly precipitation was similar to averages with the exception of August 2004 and January 2005 which were very dry, and December 2004 with more than double the average monthly precipitation. Nearly 650 mm of rain fell over a 15-day period at the end of December 2004.

Table 8.1-30 Comparison of 2004-2005 and Average Precipitation in Mine Site Area (mm)

Mine Area	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Total
2004-2005 ^(a)	5	13	8	33		31		55			239	238	
average ^(b)	49	67	59	64	66	50	22	68	217	259	253	212	1,386

^(a) Totals for April, June and November missing up to six days of data.

^(b) Period of record 1997-2005.

Table 8.1-31 Comparison of 2004-2005 and Average Precipitation in Tailings Area (mm)

Tailings Area	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Total
2004-2005	349	326	312	224	64	119	122	134	775	273	309	316	3,322
long-term ^(a)	315	271	263	276	200	128	116	155	311	403	425	479	3,343

^(a) Period of record 1948-2004.

Numbers have been rounded for presentation purposes.

4.3 EVAPOTRANSPIRATION

4.3.1 General

Regional evapotranspiration is discussed in Section 2.4. Using the assumption presented in Section 2.4 and the available local climate data, actual evapotranspiration at the mine site is estimated at 750 mm per year. Evapotranspiration rates for the Torotorofotsy wetlands are expected to be closer to potential ET due to continuous water availability and are estimated at 900 mm/year.

Actual ET in the tailings area is estimated at 1,300 mm per year. This is consistent with an annual ET of 1,325 mm calculated for rice cultivation using the Penman-Montieth method based on three years of monthly climate data from Toamasina. It is also consistent with the estimate of actual ET of 1,275 mm provided by the Atlas of Madagascar (referenced in Chaperon et al. 1993).

Estimates of annual evapotranspiration are summarized in Table 8.1-32. Monthly ET amounts were derived based on the annual totals and the percent contribution of each month to the total, as derived from available pan evaporation data for Andasibe (Perinet) and piche evaporation data for Toamasina (see Table 8.1-33).

Table 8.1-32 Annual Evapotranspiration for the Project Areas

Area	Location	Actual ET (mm)
mine	mine development	750
	Torotorofotsy wetlands	900
tailings	tailings impoundment	1,300

Table 8.1-33 Derived Monthly Evapotranspiration (mm)

Area	Location	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
mine	mine areas	75	75	83	68	75	60	45	45	45	45	53	83	750
	Torotorofotsy wetlands	90	90	99	81	90	72	54	54	54	54	63	99	900
tailings	tailings area	137	124	123	101	115	92	92	91	95	100	107	124	1,300

Note: Numbers have been rounded for presentation purposes.

4.3.2 2004-2005 Conditions

Available evapotranspiration data is compared to expected averages in Table 8.1-34. There is no evaporation information available for the tailings area for the 2004-2005 period.

Table 8.1-34 Comparison of 2004-2005 and Average Evapotranspiration in Mine Site Area (mm)

Mine Area	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Total
2004-2005	78	52		50		85		55			95		
average ^(a)	120	115	107	100	95	75	59	50	51	60	79	94	1,005

^(a) Period of record 1997 – 2005.

4.4 STREAMFLOW AND RUNOFF

4.4.1 General

Annual and seasonal monthly runoff estimates for the project areas are provided in Table 8.1-35. Discharges for daily low flow and peak flow conditions are provided in Table 8.1-36. The runoff estimates are based on the 2004 to 2005 monitoring period, and have not been adjusted to reflect long-term rainfall conditions. They do not, therefore, provide guidance on typical runoff rates from the watershed.

In the mine site area, the dry season flows reflect rainfall that is believed to be below average. Average precipitation at Moramanga was below average between 1997 and 2002. Precipitation during the 2004 dry season at the mine site was lower than the 1997 to 2005 average, though February and March wet season precipitation was close to the 1997 to 2005 average.

The wide range in dry season flows is believed to be associated with groundwater discharge from the Ambavalabe ridge. The lowest flows are from watersheds with little or no groundwater recharge from the ridge, while the higher flows are for runoff from watersheds capturing significant groundwater recharge. Wet

season peak flows are linked to short-duration rainfall events. Insufficient data are available to determine the return periods of the flows recorded in 2004 and 2005.

Based on available rainfall information, flows recorded in the tailings area are believed to represent fairly typical conditions. Total annual rainfall between April 2004 and March 2005 was very close to the long-term average for the area, despite a noticeably drier August and slightly wetter December to January period. The resulting peak flows may have been slightly elevated compared to average conditions, however there is insufficient data to determine the return periods of these flows. Flows in the middle basin dropped noticeably between October and December and did not follow the trends of the upper and lower watershed. The cause of this is unclear and may not be representative of typical conditions.

**Table 8.1-35 Typical Derived Monthly and Annual Runoff for Project Areas
(Based on 2004-2005 Monitoring Program)**

Project Area	Sub-Area	Monthly Runoff (mm)			Annual Runoff (mm)
		Early Dry Season (April/May)	Late Dry Season (October/November)	Peak Wet Season (January – March)	
mine area	mine	25-60	6-30	80-100 (draining south/west) 150 (draining north)	500-600
	Torotorofotsy	25-35	5-10	100-150	500-600
	Mangoro	50	15	120-240	600-800
tailings, plant, port areas	tailings	150	50	100 (upper basin) 225 (lower basin)	1,700
	Ivondro	n/a	50	200	1,270 ^(a)
pipeline ^(b)	km 0-15 ^(b)	25-35	5-10	100-150	500-600
	km 15-25 ^(c)	50	15	140	730
	km 25-100 ^(d)	90	30	175	1,100
	km 100-130 ^(e)	125	40	200	1,500
	km 130-187 ^(f)	150	50	225	1,700

^(a) Based on Table 8.1-11 (Chaperon et al 1993).

^(b) Runoff along the pipeline is estimated by interpolation between the mine area and tailings area; based on annual precipitation of 1,750 mm.

^(c) 2,000 mm.

^(d) 2,500 mm.

^(e) 3,000 mm.

^(f) 3,300 mm.

Table 8.1-36 Derived Daily Extreme Flows for Project Areas (Based on 2004-2005 Monitoring Program)

Project Area	Sub-Area	Extreme Daily Flows (l/s/km ²)	
		Low Flows	Peak Flows
mine area	mine area	2-10	100-300
	Torotorofotsy	1	100-200
	Mangoro	4	70-200
tailings, plant and port areas	tailings	10	400
	Ivondro	15	700
pipeline ^(a)	km 0-15 ^(b)	1	150
	km 15-25 ^(c)	3	240
	km 25-100 ^(d)	8	410
	km 100-130 ^(e)	12	600
	km 130-187 ^(f)	15	700

^(a) Based on Table 8.1-11 (Chaperon et al 1993).

^(b) Runoff along the pipeline is estimated by interpolation between the mine area and tailings area; based on annual precipitation of 1,750 mm.

^(c) 2,000 mm.

^(d) 2,500 mm.

^(e) 3,000 mm.

^(f) 3,300 mm.

4.4.2 Observed 2004-2005 Conditions

Results of the 2004-2005 hydrometric monitoring program are discussed in Section 3.5.

5 REFERENCES

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VOLUME I
APPENDIX 8.1
ATTACHMENT 1
HYDROGRAPHS

Figure 1 **Discharge Hydrograph for Mine Area Stations**

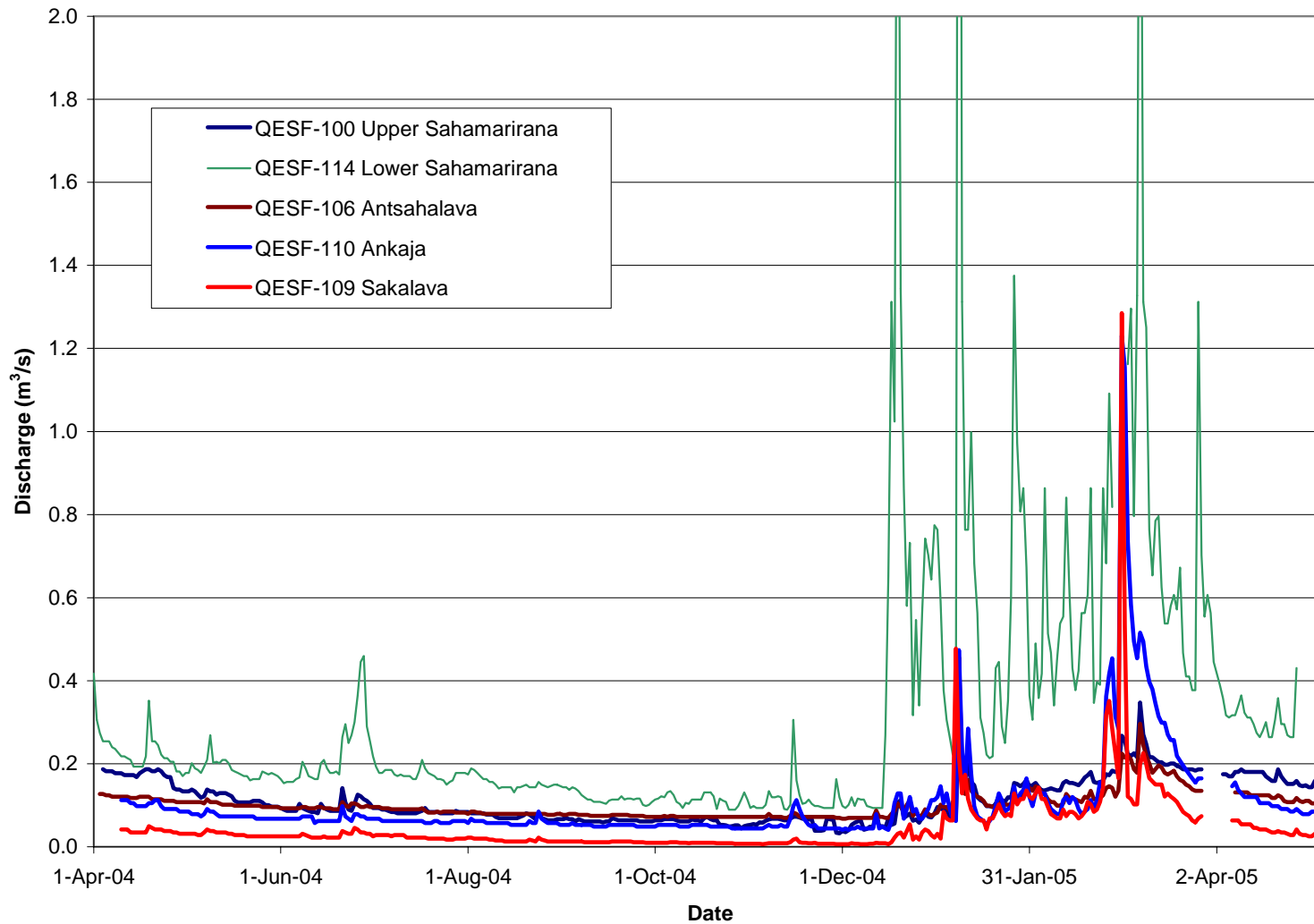


Figure 2 Discharge Hydrograph for Torotorofotsy Area Stations

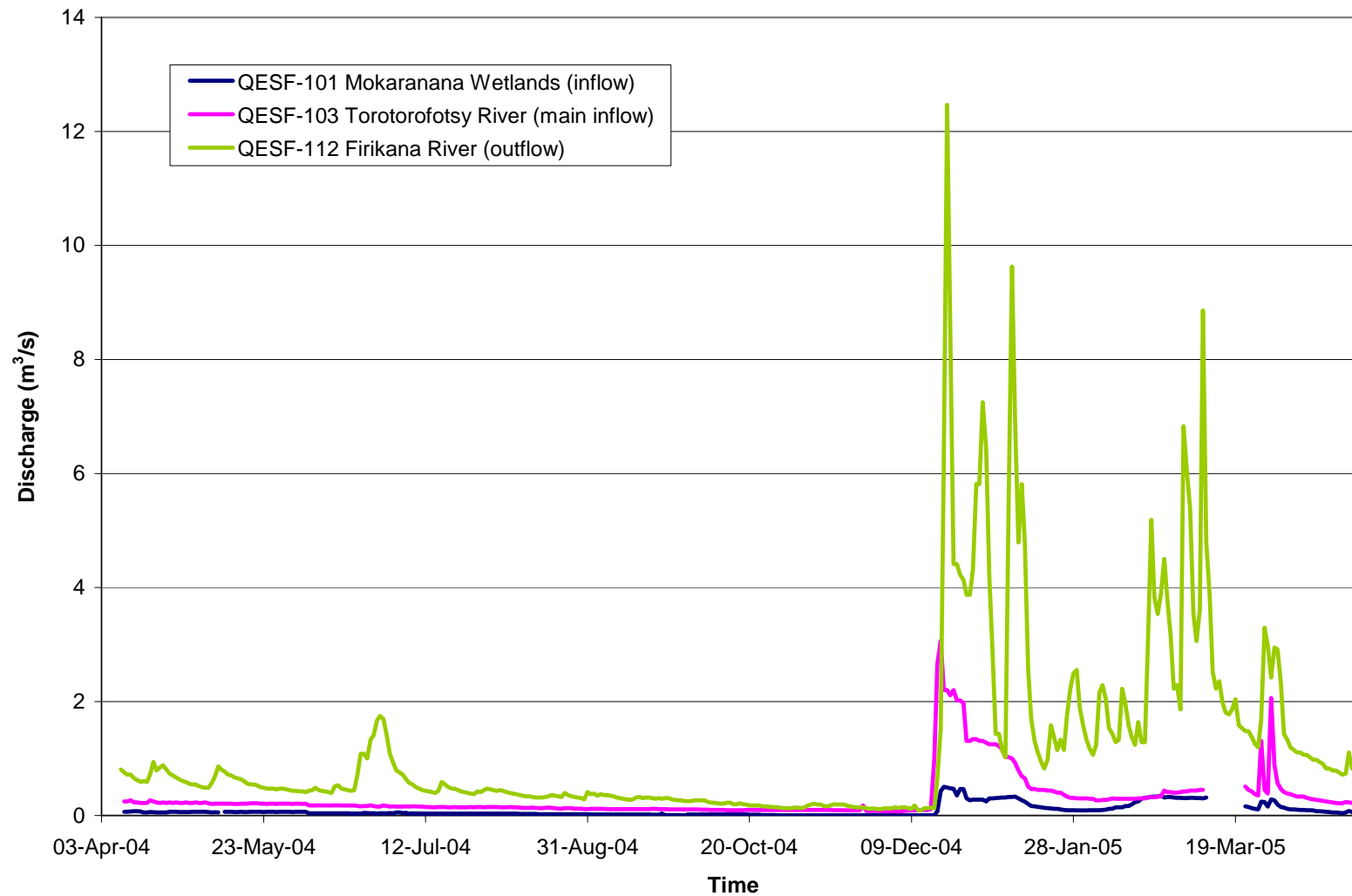


Figure 3 Discharge Hydrograph for Tailings Area Stations

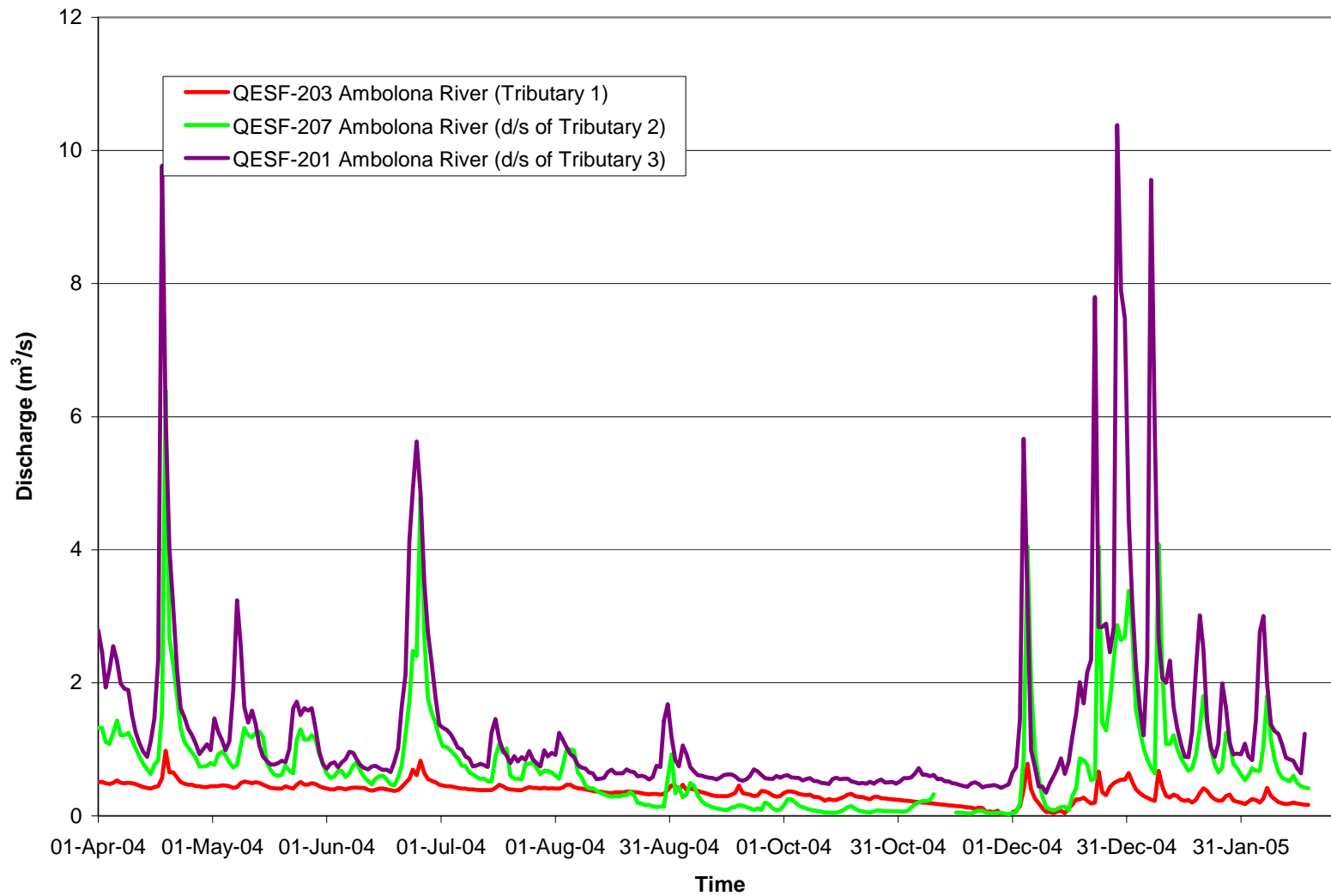


Figure 4 Discharge Hydrograph for Large River Stations

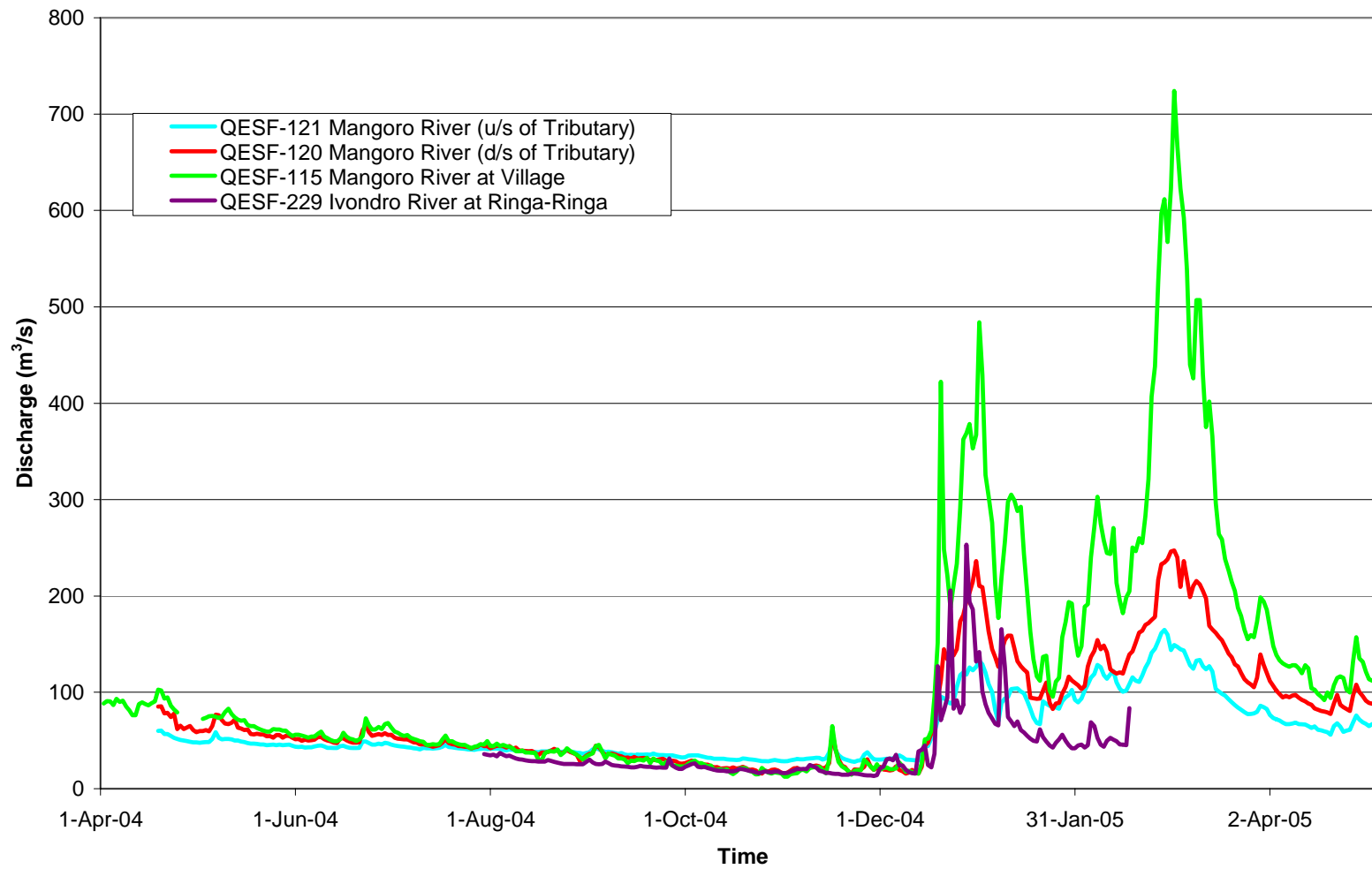


Figure 5 Unit Discharge Hydrograph for Mine Area Stations

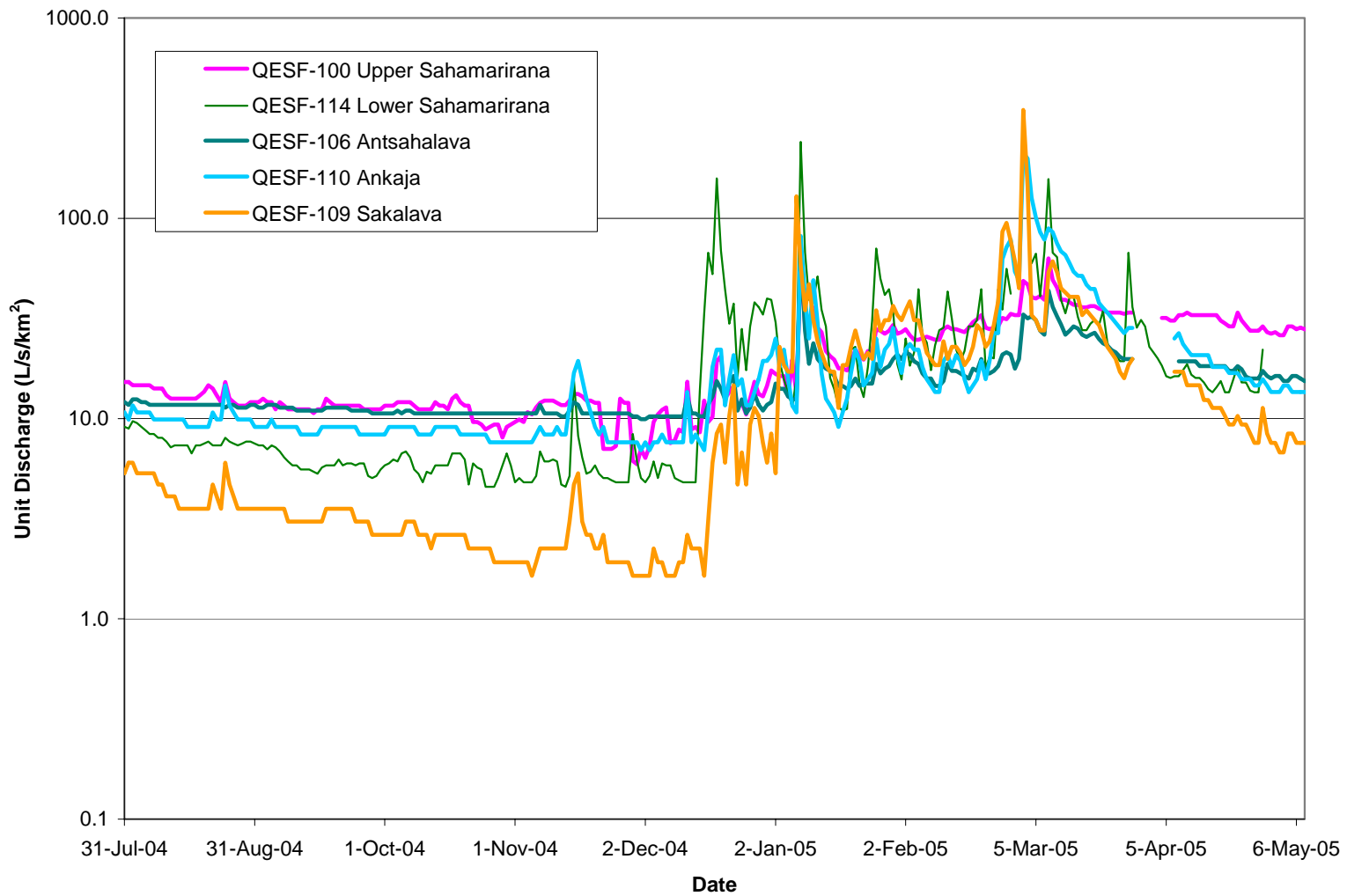


Figure 6 Unit Discharge Hydrograph for Torotorofotsy Area Stations

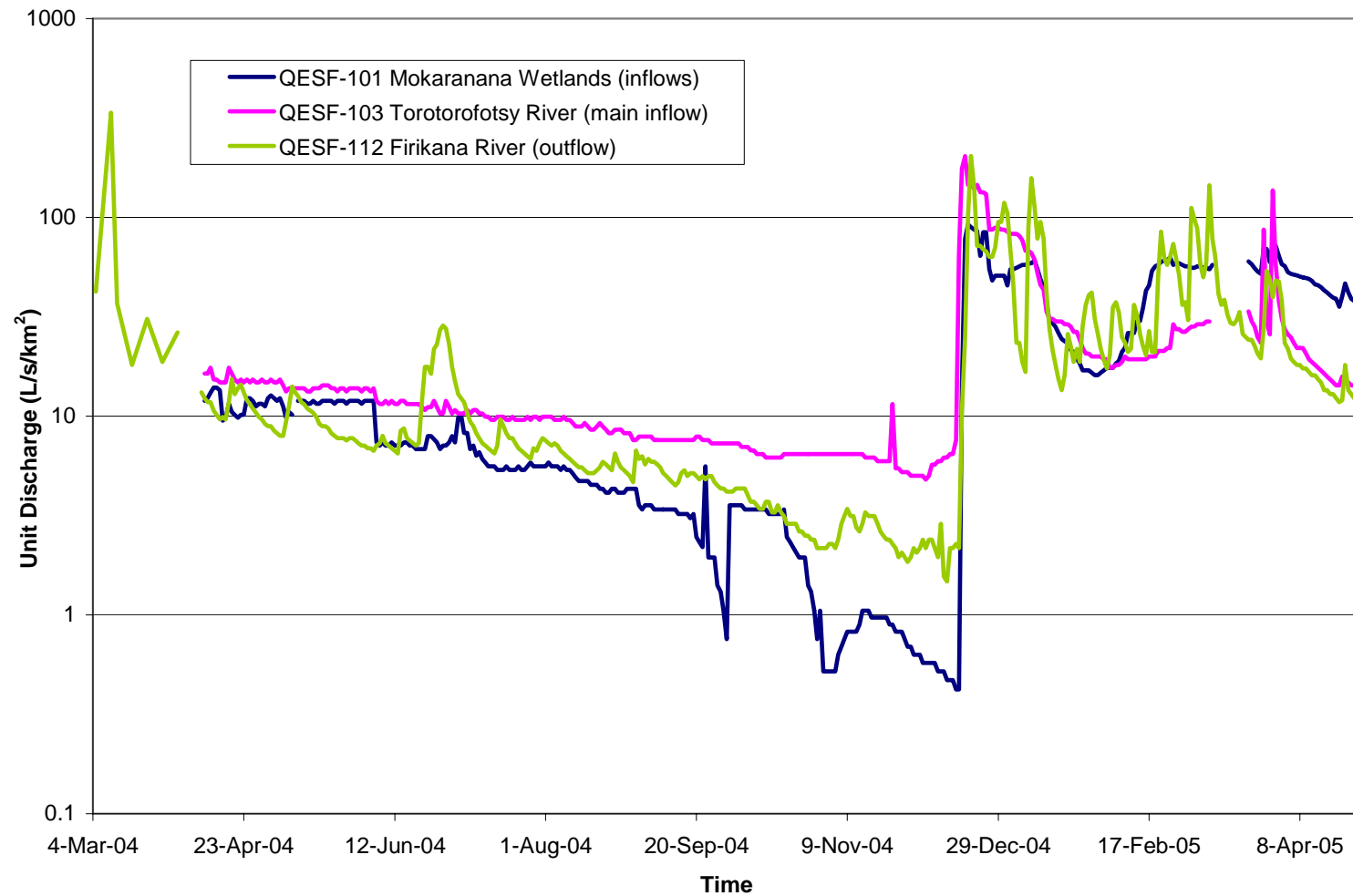


Figure 7 Unit Discharge Hydrograph for Tailings Area Stations

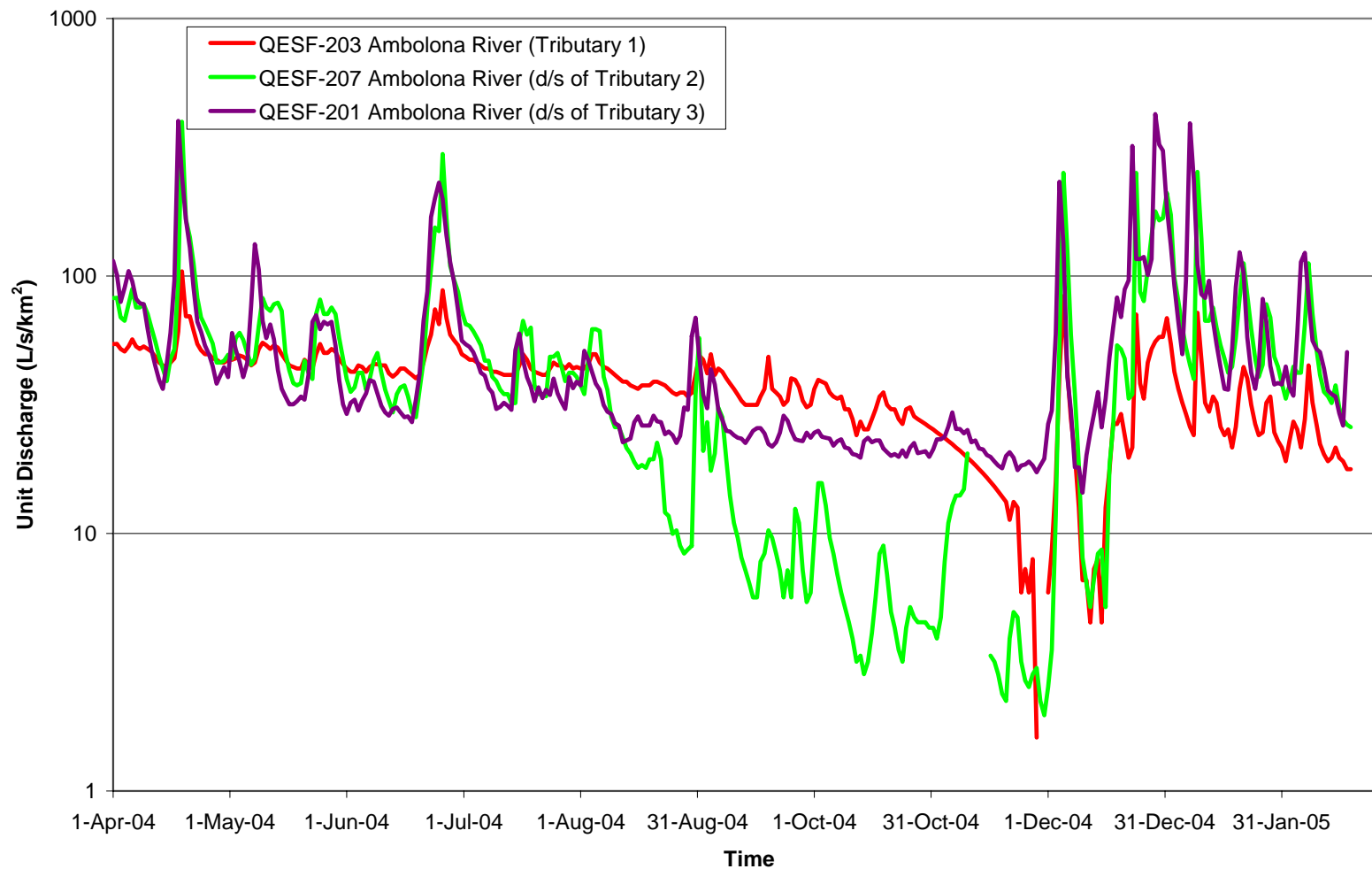
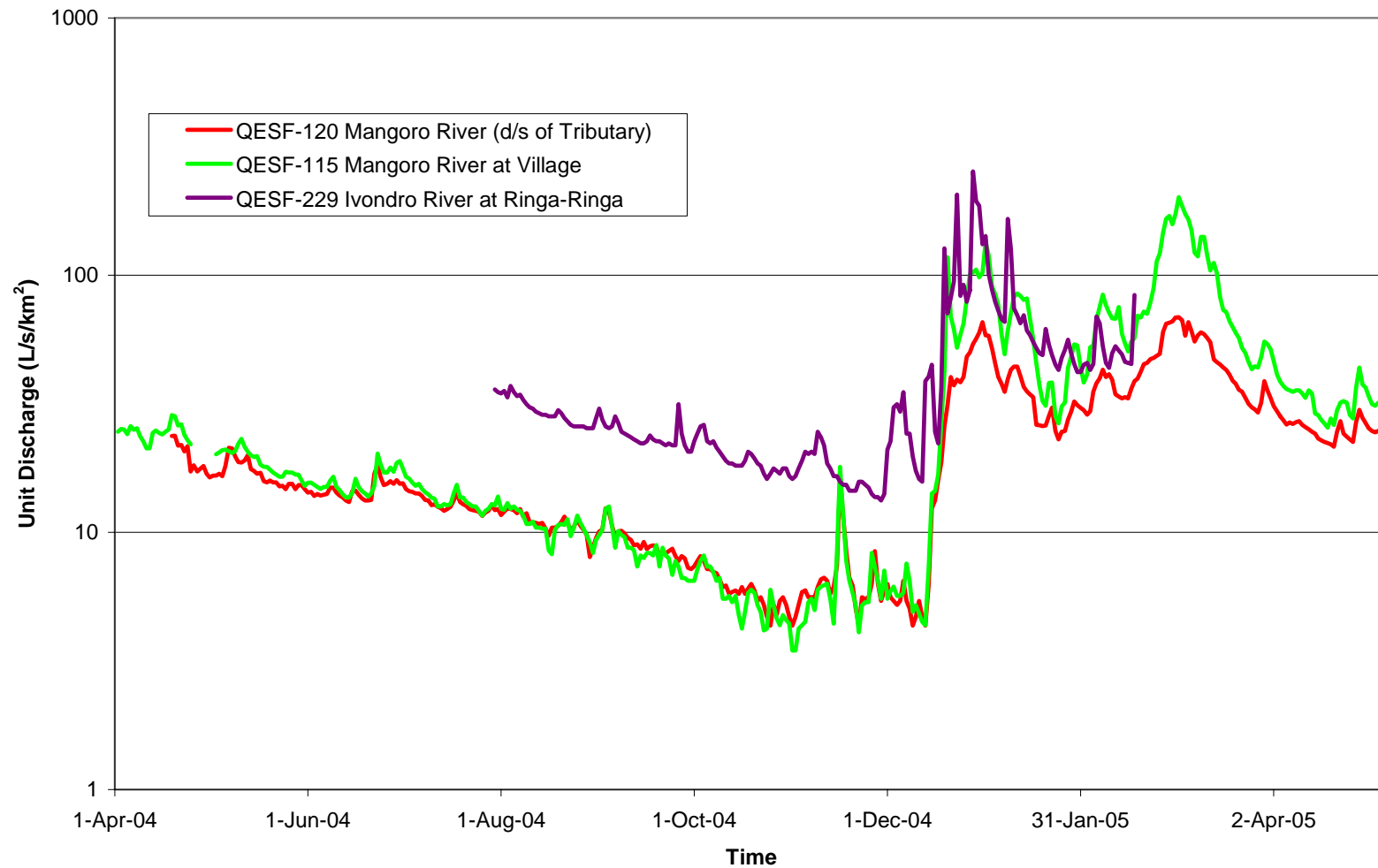


Figure 8 Unit Discharge Hydrograph for Large River Stations



VOLUME I: PHYSICAL APPENDICES
APPENDIX 8.2 – ENVIRONMENTAL ASSESSMENT

HYDROLOGY

Submitted to:
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1 HYDROLOGY MODEL INPUTS AND ASSUMPTIONS

Table 8.2-1 provides a summary of inputs and assumptions used to estimate monthly wet season basin flows. During operations, the drainage areas associated with each runoff collection pond will change as topographic features are altered and new areas are disturbed and subsequently reclaimed. The effective runoff coefficients also change to reflect different distributions of active mine areas, stockpiles, reclaimed, and undisturbed areas. The magnitude and duration of impacts is moderated by the phasing of the development. Flow moderation into the downstream reaches can also be achieved through storage augmentation and flow diversion to the ore preparation plant. In the Analamay area during operations, an additional volume will be diverted directly from active mine and stockpile areas to the ore processing plant if water quality from these areas prevents release to the downstream environment (see Water Quality assessment, Volume B, Section 3.9).

The mine water management computer model prioritizes monthly pond releases so that they are equivalent to estimated baseline volumes. It then diverts excess water for mine slurry plant water supply (up to 1,000 m³/h if available), and finally releases any remaining pond volumes to the downstream reaches. During the wet season, rainfall and runoff is high and under normal conditions there are large volumes of water released to the environment. In the dry season, baseline flow volumes are maintained by collected surface runoff and slurry plant needs are met primarily using water from the Mangoro River pipeline.

Table 8.2-1 Inputs and Assumptions for Deriving Pond Outflows for the Hydrologic Model

Scenario	Model Inputs and Assumptions	Basin and Runoff Collection Pond					
		Antsahalava Ambatovy North	Sahaviara Ambatovy Waste Stockpile	Sahamarirana Ambatovy South	Torotorofotsy Analamay South	Sakalava Analamay North-east	Ankaja Analamay North-west
baseline	drainage area (ha)	500	189	387.5	456.4	396.1	647.7
	runoff coefficient	0.4	0.4	0.4	0.4	0.4	0.4
year 4	drainage area (ha)	553	194	402	456	396	649
	effective runoff coefficient	0.51	0.55	0.58	0.4	0.4	0.48
	change in runoff to pond ^(a)	40%	41%	51%	5%	6%	20%
	volume diverted from pond ^(b) (m ³ /month)	249,000	87,000	249,000	0 ^(c)	0 ^(c)	146,400
year 10	drainage area (ha)	551	195	410	456	396	627
	effective runoff coefficient	0.52	0.55	0.59	0.52	0.52	0.51
	change in runoff to pond ^(a)	42%	42%	55%	31%	29%	23%
	volume diverted from pond ^(b) (m ³ /month)	154,000	51,000	183,000	12,4000	73,000	146,000
year 15	drainage area (ha)	555	188	437	456	386	636
	effective runoff coefficient	0.57	0.59	0.54	0.52	0.62	0.49
	change in runoff to pond ^(a)	58%	47%	51%	31%	51%	21%
	volume diverted from pond ^(b) (m ³ /month)	256,000	51,000	146,000	110,000	168,000	0
year 20	drainage area (ha)	545	188	426	456	386	636
	effective runoff coefficient	0.59	0.6	0.53	0.48	0.6	0.58
	change in runoff to pond ^(a)	60%	49%	47%	19%	47%	41%
	volume diverted from pond ^(b) (m ³ /month)	249,000	51,000	117,000	37,000	132,000	146,000
post-closure	drainage area (ha)	545	199	416	457	386	637
	effective runoff coefficient	0.46	0.48	0.48	0.44	0.46	0.46
	% change in runoff	25%	26%	28%	9%	13%	13%

(a) Change in runoff volume to pond location compared to runoff under baseline conditions.

(b) Model assumption of excess runoff that is diverted from the collection pond to reduce high volume releases to downstream reaches during the wet season. Total diverted volume is equivalent to the ore preparation plant requirements assumed to be 1,000 m³/h.

(c) Analamay South and North-east runoff collection ponds are not operational in Year 4.

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VOLUME I: PHYSICAL APPENDICES

APPENDIX 9.1

WATER QUALITY BASELINE

Submitted to:

Dynatec Corporation

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Attachment 2	Universal Transverse Mercator (UTM) Coordinates of Station Locations
Attachment 3	Background General Water Quality Information

1 INTRODUCTION

1.1 BACKGROUND

The Ambatovy Project (the project) will involve the development of a nickel laterite mine and processing facilities. Additional infrastructure to support mining will include a slurry pipeline and expansion of the existing port at Toamasina on the east coast of Madagascar.

Historical water quality sampling at locations around the mine area was conducted between 1996 and 1998 as part of an original Phelps Dodge project. In 2004, water and sediment quality monitoring was conducted in the mine, slurry pipeline, process plant and tailings areas to augment the available historical water quality data for the mine area, and to provide baseline water and sediment quality data for other locations that may potentially be affected by the project (slurry pipeline, tailings and plant facility areas).

This report presents information on baseline water and sediment quality of surface water bodies located in the vicinity of the project.

1.2 STUDY AREA

The Ambatovy and Analamay mine ore bodies lie generally on a high plateau and a drainage divide; the headwaters of several basins originate within the ore body area. A major internationally-recognized wetlands system, the Torotorofotsy, is located immediately downstream of a portion of the mine site. Further east, towards the Indian Ocean, are the proposed tailings facility and process plant areas. Connecting these two areas and the mine area is the proposed route for the slurry pipeline, which crosses numerous watercourses.

The water quality study area for the project encompasses water bodies (rivers, streams, ponds, irrigation channels and wetlands) within the drainage basins which may potentially be influenced by project activities occurring in the mine area, slurry pipeline corridor, process plant and tailings facility areas.

1.3 STUDY OBJECTIVES

The following objectives were identified for the baseline study:

- describe and discuss baseline water and sediment quality characteristics in water bodies within the project area;
- compare water quality to Madagascar classification system for water quality;
- compare water and sediment quality information with regulatory guidelines for the protection of aquatic life (Canadian Council of Ministers of the Environment and U.S. Environmental Protection Agency) and drinking water quality (WHO); and
- where possible, discuss temporal and spatial patterns in water quality parameters, based on the 2004 and historical data.

The approach taken in this report is to document in detail methods and findings from water and sediment quality sampling conducted in 2004. Wherever possible, comparison of the 2004 data with historical data is provided, in order to identify potential changes that may have occurred with respect to key water quality parameters since the 1996 to 1998 studies.

2 METHODS

2.1 FIELD METHODS

2.1.1 Water Quality Sampling

Methods for water quality sampling in 2004, including information on station locations, sampling and field measurement procedures, and laboratory analysis, are presented in the following sections. Field methods and water quality data from the historical water quality sampling campaigns are presented in Volume I-9.1, Attachment 1.

2.1.1.1 Sampling Locations

Water quality sampling occurred within four general areas in 2004, including:

- 23 stations at the proposed mine site (Figure 9.1-1);
- 12 stations along the proposed slurry pipeline route (Figure 9.1-2);
- 18 stations near the proposed process plant site (Figure 9.1-3); and
- 15 stations at the proposed tailings facility site (Figure 9.1-3).

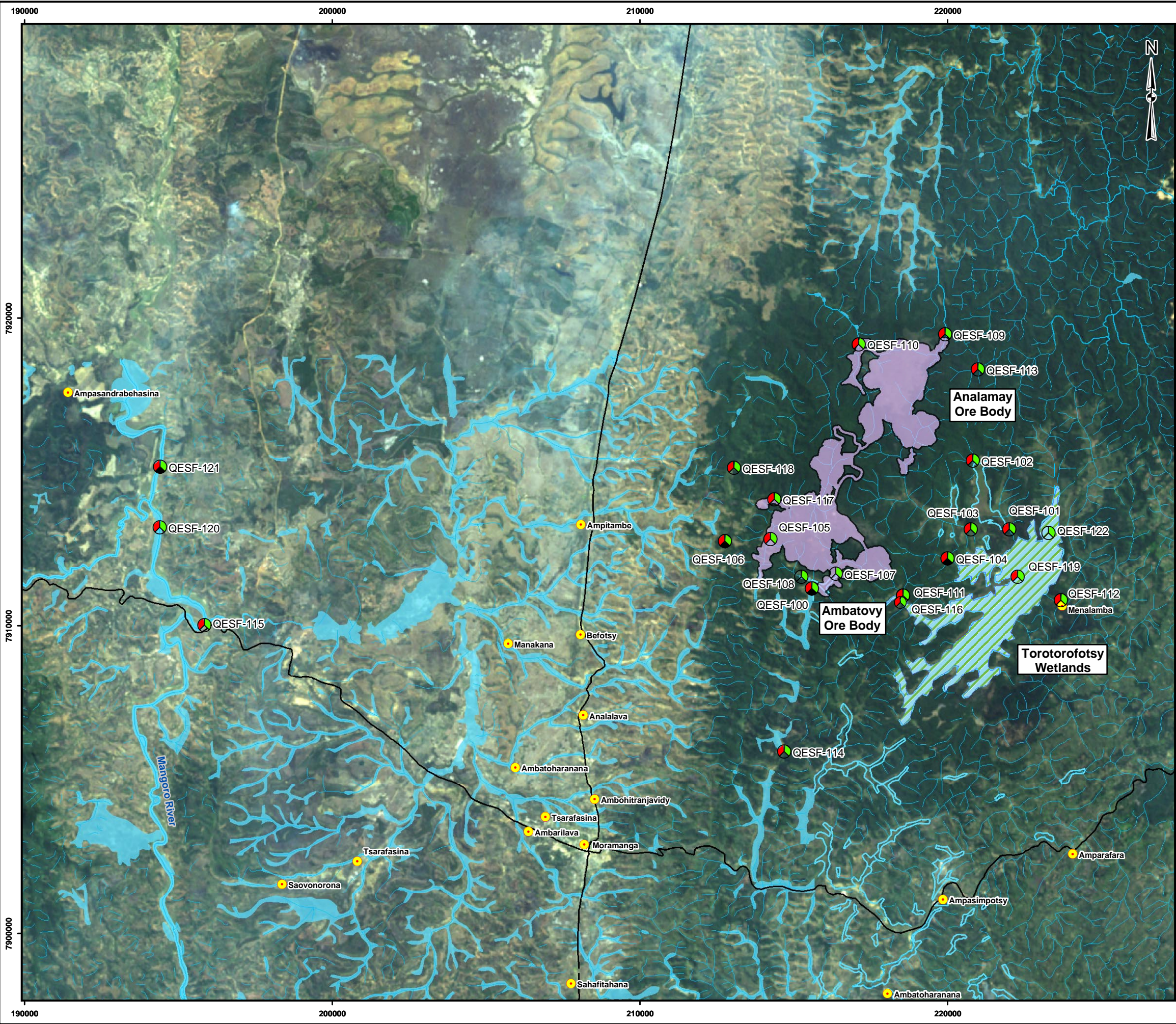
Over fifteen distinct water systems were sampled, including major systems such as the Mangoro River, the Torotorofotsy wetland system, the Sahamarirana River, the Ambolona, the Ivondro and the Pangnalanes Canal (Table 9.1-1). Sampling was conducted within the different types of water bodies located within each of the four areas including rivers, streams, wetlands, irrigation ditches, canals, drainage ditches and ponds (Table 9.1-2). Water quality sampling was conducted during both the wet and dry seasons to describe seasonal differences in water quality parameters at the various areas.

Water quality sampling during the wet season was conducted between February 28 and April 19, 2004; dry season sampling occurred between November 2 to 29, 2004. Only *in-situ* field water quality measurements were collected along the slurry pipeline stations (in September and October 2004, and in January and February, 2005).

Sampling locations were based on a number of considerations including:

- historical (1996 to 1998) sampling locations;
- the proposed mine area footprint;
- proposed locations for mine area infrastructure (e.g., water intakes);
- the proposed tailings facility and processing plant footprints; and
- the proposed route of the slurry pipeline.

i:/2003/03-1322/03-1322-172/mxd/Water_Quality/Fig9.1-1_Minesite_WQ_StaffGauges_WetDrySeason.mxd



LEGEND

POPULATION CENTRE

ROAD

STREAM OR RIVER

OPEN WATER

WETLANDS

MINE SITE (ORE BODY)

WATER QUALITY SAMPLE DURING DRY SEASON

WATER QUALITY SAMPLE DURING WET SEASON

SEDIMENT QUALITY SAMPLE

REFERENCE
Landsat 7 Mosaic Image; Captured April/Sept. 2001
Datum: WGS 84 Projection: UTM Zone 39S




PROJECT

AMBATOVY PROJECT

TITLE

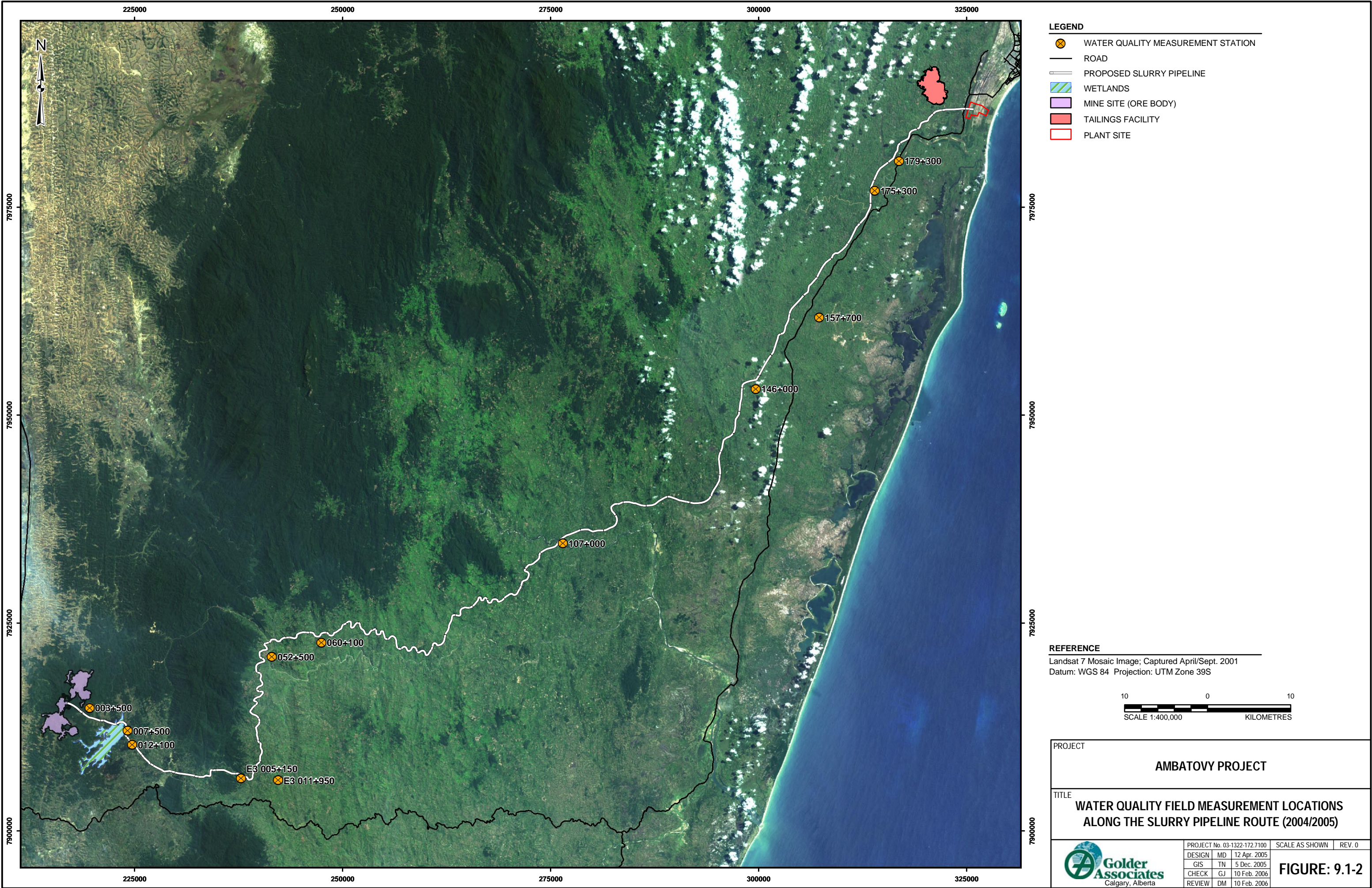
MINE AREA WATER AND SEDIMENT
QUALITY MONITORING LOCATIONS (2004)

Golder Associates
Calgary, Alberta

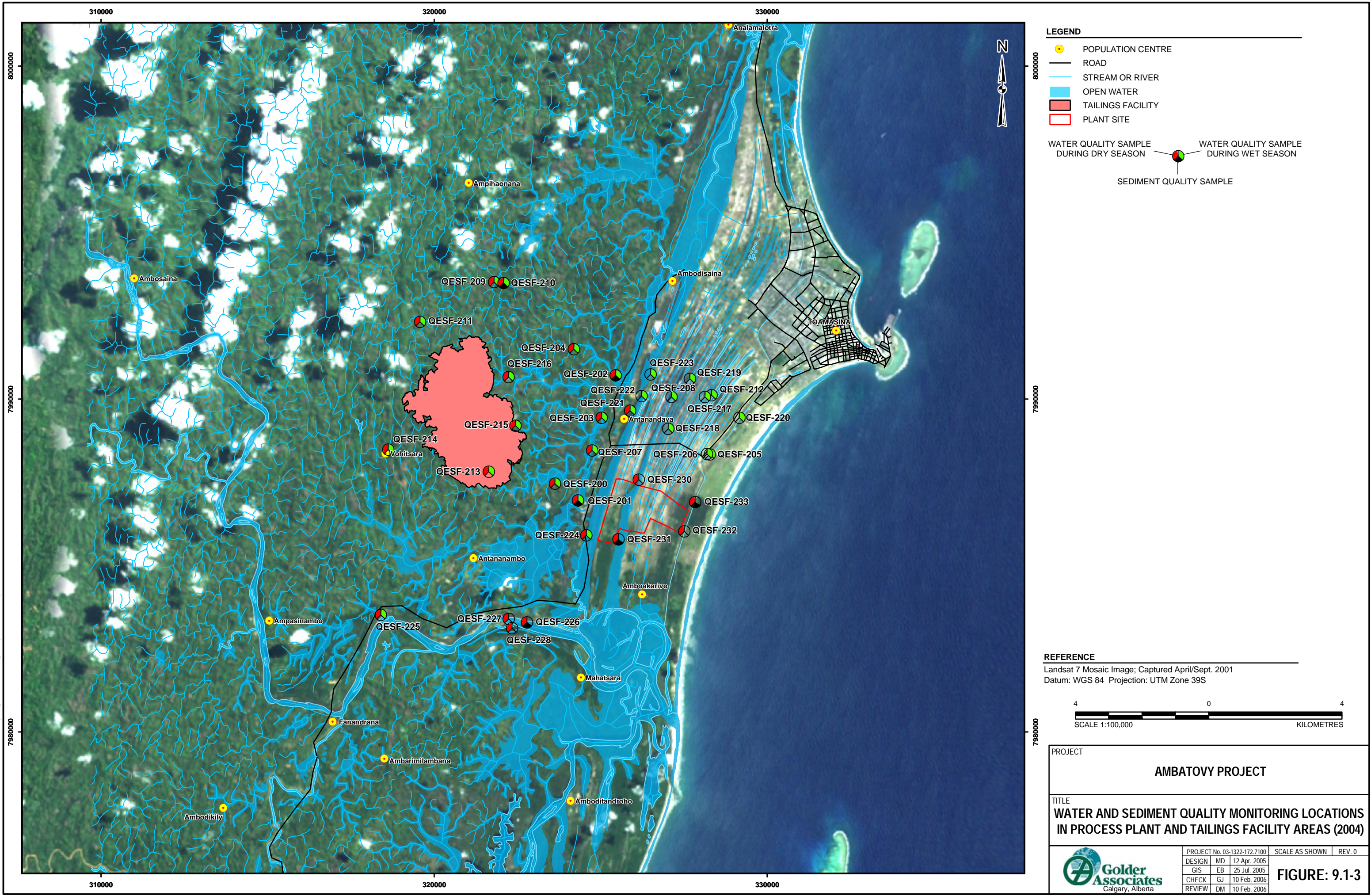
PROJECT No.	03-1322-172.7100	SCALE AS SHOWN	REV. 0
DESIGN	MD 12 Apr. 2005		
GIS	TN 5 Dec. 2005		
CHECK	GJ 10 Feb. 2006		
REVIEW	DM 10 Feb. 2006		

FIGURE: 9.1-1

i:/2003/03-1322/03-1322-172/mxd/Water_Quality/Fig9.1-2_PipelineLocations.mxd



i:/2003/03-1322/03-1322-172/mxd/Water_Quality/Fig9.1-3 Tailings_Hydro_WetDrySeason.mxd



Global Positioning System (GPS) was used to record the Universal Transverse Mercator (UTM) coordinates of each water and sediment quality monitoring location (Table 1 in Volume I-9.1, Attachment 2).

Table 9.1-1 Basins Monitored in 2004

Project Area	Basin	Station	Watercourse Name
Mine Area	Sahamarirana	QESF-107	Western tributary to upper Sahamarirana River
		QESF-108	Eastern tributary to upper Sahamarirana River
		QESF-100	Upper Sahamarirana River
		QESF-114	Lower Sahamarirana River
	Antsahalava	QESF-106	Antsahalava River
		QESF-117	Antsahalava River (approximately 3 km upstream of QESF-106)
	Ankaja	QESF-110	Ankaja River
	Sakalava	QESF-109	Sakalava River
	Marinjo	QESF-113	Marinjo River east of Analamay
	Sahariara	QESF-105	Upstream of Sahariara River
	Sahevo	QESF-118	Sahevo River
	Torotorofotsy	QESF-103	Torotorofotsy River (upstream of wetlands)
		QESF-104	West Tributary to Torotorofotsy wetlands
		QESF-101	Outlet of Mokaranana wetlands
		QESF-102	Upstream of Mokaranana wetlands (northeast tributary)
		QESF-112	Firikana River (outlet of Torotorofotsy wetlands)
		QESF-111	Eastern tributary to western arm of Torotorofotsy wetlands
		QESF-116	Western tributary to western arm of Torotorofotsy wetlands
		QESF-119	Torotorofotsy wetlands
		QESF-122	Northeast arm of Torotorofotsy wetlands
	Mangoro	QESF-121	Mangoro River upstream of tributary
		QESF-120	Mangoro River downstream of tributary (approximately 4 km upstream of QESF-115)
		QESF-115	Mangoro River near Village

Table 9.1-1 Basins Monitored in 2004 (continued)

Project Area	Basin	Station	Watercourse Name
Process Plant	Ivondro	QESF-225	Sahave River, tributary to Ivondro
		QESF-226	Ivondro River
		QESF-227	Ivondro River upstream of QESF-226
		QESF-228	Ivondro River upstream of QESF-226
	Pangnalanes Canal	QESF-232	Pangnalanes Canal
		QESF-233	Pangnalanes Canal downstream of QESF-232
		QESF-205	Pangnalanes Canal downstream of QESF-233
		QESF-220	Pangnalanes Canal downstream of QESF-205
Tailings Area	Ambolona	QESF-203	Ambolona (Tributary 1)
		QESF-216	Wetland channel upstream of QESF-207 within Tributary 1
		QESF-207	Ambolona (downstream of Tributary 2)
		QESF-215	Wetland channel upstream of QESF-207 within Tributary 2
		QESF-201	Ambolona (downstream of Tributary 3)
		QESF-224	Tributary of Ambolona (downstream of QESF-201)
		QESF-200	Irrigation channel upstream of QESF-201 within Tributary 3
		QESF-213	Wetland channel upstream of QESF-200 within Tributary 3
	Ranomaioloy	QESF-209	Western tributary of Ranomaioloy River
		QESF-210	Eastern tributary of Ranomaioloy River
	Sangalaoatra	QESF-202	Sangalaoatra River north of Antanandave
		QESF-204	Sangalaoatra River northwest of Antanandave
	Andranofisotro	QESF-211	Andranofisotro (1.2 km west of Bekalao)

Table 9.1-2 Water Quality Station Locations Monitored in 2004

Area	Grouping of Stations	Number of Stations		Station Names
		Wet Season	Dry Season	
Mine	streams	10	10	QESF 102, 103, 104, 105, 106, 109, 110, 112, 113 and 117
	channel in wetlands	3	3	QESF 101, 118, and 119
	irrigation channels	7	4	QESF 100, 107 ^(w) , 108 ^(w) 111, 114, 116, and 122 ^(w)
	Mangoro River	3	3	QESF 115, 120 and 121
Slurry pipeline	streams	2	8	003+500 ^(d) , 007+500 ^(d) , 012+100 ^(d) , 052+500 ^(w) , 060+100 ^(w) , 107+000 ^(d) , 175+300 ^(d) , 157-700 ^(d) , E3 005+150 ^(d) , E3 011+950 ^(d)
	Ivondro River	0	1	179+300 ^(d)
	Morongolo River	0	1	146+000 ^(d)
Process plant	Ivondro River	0	3	QESF 226 ^(d) , 227 ^(d) and 228 ^(d)
	streams	1	1	QESF-225
	Pangalanes Canal	2	2	QESF-205 ^(w) , 220 ^(w) , 232 ^(d) and 233 ^(d)
	ponds	7	2	QESF-208 ^(w) , 212 ^(w) , 217 ^(w) , 218 ^(w) , 219 ^(w) , 223 and 224
	drainage ditch	1	0	QESF-206 ^(w)
	channel in wetlands	0	2	QESF 230 ^(d) and 231 ^(d)
Tailings facility	streams	4	4	QESF 209 to 211, 214
	channel in wetlands	7	7	QESF 202 to 204, 207, 213, 215, and 216
	irrigation channels	2	2	QESF 200 and 201
	pond	2	0	QESF-221 ^(w) and 222 ^(w)

^(w) = Monitored in the wet season only.

^(d) = Monitored in the dry season only.

2.1.1.2 Field Measurements

Supporting water quality data were measured at each station and included flow rate, turbidity, temperature, conductivity, Total Dissolved Solids (TDS), dissolved oxygen (DO), pH and redox potential. Turbidity was measured with a Lamothe turbidity meter (model 2020) and all other field parameters were measured with a Multi-probe YSI meter (model 556).

2.1.1.3 Water Quality Sampling

Water quality samples were collected from a boat or by wading into the water. To collect a sample, a clean bottle supplied by the laboratory was immersed about 30 cm below the water surface in an upstream direction. Where it was necessary to reuse sample bottles, bottles were triple rinsed with the ambient water before collecting the sample. When applicable, samples were filtered and preserved in the field, and placed in an ice-filled cooler, at 4°C.

Water samples were shipped daily on ice for analysis of coliforms at Institut Pasteur Laboratory. Total suspended solids (TSS) and TDS samples were shipped to Jirama Laboratories in Madagascar during the wet season and to Inspectorate Laboratories in South Africa during the dry season. Dry season samples for TDS, TSS and biochemical oxygen demand (BOD) were frozen for shipment, as per laboratory instructions.

If a sediment sample was also taken at the same station, water quality sampling and field measurements were completed before collecting the sediment samples, in order to minimize potential for contamination artifacts.

2.1.1.4 Laboratory Analysis

Water quality parameters analyzed in 2004 and applicable detection limits are summarized in Table 9.1-3. Inspectorate M & L Laboratories of South Africa completed most of the analysis with the following exceptions:

- samples for total coliforms were analyzed at Institute Pasteur Laboratory, Madagascar;
- samples for TDS and TSS collected during the wet season were analyzed at Jirama Laboratories in Madagascar; and
- samples for antimony, arsenic, mercury and selenium collected during the dry season were analyzed at Mhlathuze Water, in South Africa.

Through discussions with the Inspectorate M & L Laboratories, it was possible to achieve lower detection limits during the second field campaign in the dry season.

Table 9.1-3 Water Quality Parameters Analyzed in 2004

Parameter	Units	Detection Limits	
		Wet Season	Dry Season
Conventional Parameters			
pH value	pH Units	n/a	n/a
Total alkalinity	mg/L	1	1
Total dissolved solids	mg/L	1	1
Total suspended solids	mg/L	1	1
Conductivity	μS/cm ^(w) mS/m ^(d)	1	0.1
Nutrients			
Free and saline ammonia	mg/L	0.1	0.1
Nitrate	mg/L	0.1	0.1
Nitrite	mg/L	0.1	0.1
Total Kjeldahl nitrogen ^(d)	mg/L	-	0.1
Phosphate	mg/L	0.1	0.1
Dissolved organic carbon ^(d)	mg/L	-	1
Total phosphorus ^(d)	mg/L	-	0.04
Major Ions			
Bicarbonate	mg/L	1.5	1.5
Calcium	mg/L	0.1	0.1
Chloride	mg/L	0.1	0.1
Fluoride	mg/L	0.1	0.1
Magnesium	mg/L	0.1	0.1
Potassium	mg/L	0.1	0.1
Sodium	mg/L	0.1	0.1
Sulphate	mg/L	0.1	0.1
Total Metals			
Aluminum	mg/L	0.01	0.009
Antimony	mg/L	0.1	0.0006
Arsenic	mg/L	0.01	0.0002
Barium	mg/L	0.05	0.1
Beryllium	mg/L	0.01	0.002
Bismuth ^(d)	mg/L	-	0.005
Boron	mg/L	0.01	0.006
Cadmium	mg/L	0.01	0.001

Table 9.1-3 Water Quality Parameters Analyzed in 2004 (continued)

Parameter	Units	Detection Limits	
		Wet Season	Dry Season
Chromium (total)	mg/L	0.01	0.003
Chromium (Cr ⁺⁶) ^(w)	mg/L	0.01	-
Gallium ^(d)	mg/L	-	0.002
Germanium ^(d)	mg/L	-	0.012
Gold ^(d)	mg/L	-	0.004
Cobalt	mg/L	0.01	0.001
Copper	mg/L	0.01	0.002
Indium ^(d)	mg/L	n/a	0.004
Iron	mg/L	0.01	0.01
Lead	mg/L	0.1	0.01
Manganese	mg/L	0.01	0.001
Mercury	mg/L	0.001	0.0003
Molybdenum ^(d)	mg/L	-	0.001
Nickel	mg/L	0.01	0.003
Selenium	mg/L	0.01	0.0001
Silicon ^(d)	mg/L	-	0.007
Silver ^(d)	mg/L	-	0.004
Strontium	mg/L	0.01	0.001
Thallium ^(d)	mg/L	-	0.009
Tellurium ^(d)	mg/L	-	0.012
Thorium	mg/L	0.01	0.002
Tin	mg/L	0.01	0.02
Titanium	mg/L	-	0.001
Uranium	mg/L	0.2	0.004
Vanadium	mg/L	0.01	0.002
Zinc	mg/L	0.01	0.004
Zirconium ^(d)	mg/L	-	0.001
Biological Parameters			
Total coliforms	CFU/100 ml	1	3
Organics			
Oil and grease	mg/L	0.1	0.2
Chemical oxygen demand ^(d)	mg/L	-	5
Biochemical oxygen demand ^(d)	mg/L	-	0.001

CFU = Colony forming units.

^(w) = Wet season only.

^(d) = Dry season only.

n/a = Not applicable.

- = Not analyzed.

2.1.2 Sediment Quality Sampling

2.1.2.1 Monitoring Locations

Sediment samples were collected at selected water quality stations in three main areas (Table 9.1-4), including:

- four stations at the proposed mine site (Figure 9.1-1);
- four stations at the proposed plant site (Figure 9.1-3); and
- three stations at the proposed tailings facility area (Figure 9.1-3).

Sediment sampling stations were located as close to the corresponding water quality stations as possible, in calm zones with finer sediments. Finer sediments, are likely more representative of the higher end of sediment concentrations of metals and nutrients because of their high adsorption capacity compared to coarser material.

Table 9.1-4 Sediment Quality Sampling Locations (2004)

Area	Grouping of Stations	Number of Stations	Station Names
Mine	streams	2	QESF 104 and 106
	irrigation channels	1	QESF 100
	Mangoro River	1	QESF 121
Process plant	Ivondro River	1	QESF 226
	streams	1	QESF 225
	Pangalanes Canal	1	QESF 233
	channel in wetlands	1	QESF 231
Tailings facility	streams	1	QESF 210
	channel in wetlands	1	QESF 202
	irrigation channels	1	QESF 201

2.1.2.2 Sediment Quality Sampling

A six-inch Eckman sampler was used at most sediment stations to collect sediment samples. A shovel or glass container was used at stations where the bed was highly compacted or substantial vegetative debris prevented the closure of the Eckman device. Before taking a sample, the sampling equipment was rinsed in ambient water to remove any clinging material. Care was taken to not disturb the bottom sediment before the sample was collected.

Samples for chemical analysis were placed in a glass container provided by the laboratory and stored in a cooler containing ice or in a fridge, until arrival at the Inspectorate M & L Laboratories. Samples for grain size analysis were placed in hermetic plastic bags provided by the laboratory, with no refrigeration.

2.1.2.3 Laboratory Analysis

Sediment quality parameters analyzed during the 2004 dry season are summarized in Table 9.1-5. All analysis was conducted by Inspectorate M & L Laboratories with the exception of grain size analysis, which was completed by Laboratoire National des Travaux Publics et du Bâtiment (LNTPB) in Madagascar.

Table 9.1-5 Sediment Quality Parameters Analyzed in 2004

Parameter	Units	Detection Limit
Nutrients		
Nitrogen (N)	%	0.005
Total carbon (C)	%	0.01
Carbonate as CO ₃	%	0.05
Total oxidisable carbon (C) (by calculation)	%	n/a
Available phosphorous (P)	mg/kg	0.1
Total Metals		
Aluminum (Al)	mg/kg	0.18
Antimony (Sb)	mg/kg	0.23
Arsenic (As)	mg/kg	0.44
Barium (Ba)	mg/kg	0.012
Beryllium (Be)	mg/kg	0.036
Boron (B)	mg/kg	0.12
Cadmium (Cd)	mg/kg	0.018
Calcium (Ca)	mg/kg	0.68
Cobalt (Co)	mg/kg	0.018
Copper (Cu)	mg/kg	0.03
Iron (Fe)	%	0.012
Lead (Pb)	mg/kg	0.20
Manganese (Mn)	mg/kg	0.006
Mercury (Hg)	mg/kg	0.02
Nickel (Ni)	mg/kg	0.066
Potassium (K)	mg/kg	0.09
Selenium (Se)	mg/kg	0.55
Sodium (Na)	mg/kg	0.39

Table 9.1-5 Sediment Quality Parameters Analyzed in 2004 (continued)

Parameter	Units	Detection Limit
Thallium (Tl)	mg/kg	0.19
Thorium (Th)	mg/kg	0.33
Tin (Sn)	mg/kg	0.18
Uranium (U)	mg/kg	0.078
Vanadium (V)	mg/kg	0.048
Zinc (Zn)	mg/kg	0.096
Grain Size (AFNOR)		
Cobbles (20 to 100 mm)	%	n/a
Gravels (2 to 20 mm)	%	n/a
Coarse sand (0.2 to 2 mm)	%	n/a
Fine sand (0.02 to 0.2 mm)	%	n/a
Silt (2 µm to 0.02 mm)	%	n/a
Clay (1 to 2 µm)	%	n/a

n/a = Detection limit not applicable. AFNOR (Association Française de Normalisation) standard was used by the Laboratoire National des Travaux Publics et du Bâtiment (LNTPB) to determine grain size.

2.2 QUALITY ASSURANCE/QUALITY CONTROL (QA/QC) PROCEDURES

Several Quality Assurance/Quality Control (QA/QC) procedures were used during the 2004 sampling program to ensure that field sampling, laboratory analyses, data analysis and reporting were conducted with minimal errors. This section presents an overview of the QA/QC methods used for the program. An overview of the QA/QC procedures and results for the historical data (1996 to 1998) are provided in Volume I-9.1, Attachment 1.

2.2.1 Field Quality Assurance/Quality Control (QA/QC) Procedures

The QA/QC procedures for field sampling include measures for maintaining and operating equipment (i.e., field water quality meters), field methodology, and field data records.

2.2.1.1 Equipment

The field water quality meters were regularly maintained and calibrated. Meters were calibrated using standard solutions specific to each parameter measured.

Conductivity and pH probes were calibrated daily before the sampling event, with the exception of DO and turbidity probes, which were calibrated before each sampling event. Results of the calibration and any required maintenance were recorded in a logbook.

2.2.1.2 Field Methodology

Field notes were recorded in waterproof field books. Data sheets and all sample labels were checked at the end of each field day to ensure completeness and accuracy. Samples were labelled, preserved, and shipped according to standard protocols provided by the laboratory. Each sample was given a name and a sample control number to identify it. Project-specific chain-of-custody forms were used to track the shipment and analysis of samples.

The QA/QC procedures include testing of the reliability of sample results, which was done by submitting field blanks for analyses. These samples were used to detect and reduce systematic and random errors that may occur during field sampling and laboratory procedures.

Field blanks were sample bottles filled with de-ionized distilled water in the field, at Toamasina and Moramanga. After the field blank samples were taken, these bottles remained sealed and were sent to the laboratory with the other sample collected on that date. They were used to determine if any sample contamination may have occurred during sampling, transportation and storage, or during analysis at the laboratory.

All QA/QC samples were collected in the same manner as environmental samples. The QA/QC samples were labelled with numbers so they could not be identified as QA/QC samples by the laboratory.

2.2.1.3 Data Management

Laboratory results were received digitally and organized into Excel spreadsheet format for the purposes of data validation and analysis. The following procedures were completed to validate data from the laboratory:

1. **Compare detection limits.** The requested detection limits and detection limits provided by the laboratory for individual samples were compared. Where laboratory detection limits were different than requested detection limits, the laboratory was notified and requested to clarify the reason for the change in detection limit. The project detection limits for all chemical analyses are presented in Table 9.1-3 (water quality) and Table 9.1-5 (sediment quality).

2. **Review of hold times.** Laboratories' hold times for parameters are recommended maximum time periods between when a sample is taken and when it is analyzed for a given parameter. For samples that were shipped to South Africa, hold times could not always be met due to transport logistics and the time needed to clear customs. Sample bottles for critical parameters, including TDS, TSS and BOD, were frozen to extend hold times when transported to South Africa. Hold times that substantially exceeded the laboratory-recommended hold times were reviewed and, if judged to have likely affected the results, these results were qualified. The judgment was based on the amount of time that the hold time was exceeded and the parameters analyzed.
3. **Review of data from field blanks samples.** The results from the field blank samples were reviewed to determine whether any contamination occurred during the preparation, storing, shipping or analyzing of the field blank. Any levels that were above detection limits in the field blanks were reviewed. Laboratories suggest that elements detected in field blanks must be 5 to 10 times above the method detection limit for the sampler to suspect contamination in the batch of samples (Envirotest Laboratory, pers. comm. 2005). The laboratory suggests this because of the uncertainty of the results near the detection limits. If levels in field blanks were consistently above 10 times the detection limit for a given parameter, the results for this parameter were qualified.
4. **Review of units.** The units reported by the laboratory were compared against the expected units for each parameter and matrix type. If laboratory units were inconsistent with expected units, the results were reviewed with the laboratory and the units were corrected in the spreadsheet.
5. **Proofing Sheets.** Hard copies of the laboratory results were compared to the data entered into the spreadsheets. Any incorrect data was rechecked and re-entered.

2.3 DATA ANALYSIS

Data were analyzed in Excel spreadsheets. Analysis of the data was checked on an ongoing basis for accuracy and QA/QC. Where appropriate, data were plotted to visually confirm patterns or trends. Approximately 10% of the calculations were proofed. If errors were found, then all related spreadsheet formulas were reviewed. Data or statistical results observed to be inconsistent with expected concentrations or results were investigated further. Where possible, data were copied directly from spreadsheets to the report document to avoid transcription errors.

2.3.1 Water Quality Data Analysis

The methods used to analyze the water and sediment quality data collected in 2004 are described in the following sections. Data were presented and analyzed based on individual results from both seasons and at each station. When comparing sets of data (i.e., seasonal analysis), individual results for each site were compared because most of the data were from different water bodies.

2.3.1.1 Water Quality Characterization

The results of the 2004 water quality sampling program were used to provide an initial characterization of existing water quality conditions within each of the study areas. The water quality characterization is based on the results of key physical and chemical parameters that are considered indicators of important aspects of water quality including pH, DO, major ions, acid sensitivity, TSS, nutrients and metals. Volume I-9.1, Attachment 3 provides details of the parameters used in characterizing water quality for the study areas. Because the information provided in Attachment 3 is primarily based on North American literature, this water quality characterization will likely require refinement as more data are collected through future monitoring programs.

2.3.1.2 Comparisons with Surface Water Classification System and Regulatory Guidelines

Whenever possible, results of water quality sampling were compared with the Madagascar surface water quality classification system and with regulatory guidelines from other jurisdictions for the protection of aquatic life and drinking water quality.

There are currently no water quality guidelines for the protection of aquatic life or for drinking water quality in Madagascar. However, the country has established water quality guidelines for effluent discharges, which will be used in the impact analysis. In addition, Madagascar has established a classification system of surface waters based on biological, physical and chemical factors through Decree 2003-464. The parameters and classifications are summarized in Table 9.1-6. Because results for all parameters were not available at all stations, the classification was based on only the available parameters at each station. Based on the results of all available parameters, the worst class for any given parameter was used to provide an overall classification for surface water quality at each station.

Table 9.1-6 Madagascar Classification System for Surface Water Quality

Parameters	Class A	Class B	Class C	Unclassifiable (Class HC)
Classification definition	good quality: multiple uses possible	moderate quality: non-contact recreation allowed; swimming may not be allowed	poor quality: swimming not allowed	excessive contamination: no use possible except for boating
Biological Factors				
Dissolved oxygen (mg/L)	$DO \geq 5$	$3 < DO < 5$	$2 < DO \leq 3$	$DO < 2$
5-day biological oxygen demand (BOD_5)	$BOD_5 \leq 5$	$5 < BOD_5 \leq 20$	$20 < BOD_5 \leq 70$	$BOD_5 > 70$
Chemical oxygen demand (COD)	$COD \leq 20$	$20 < COD \leq 50$	$50 < COD \leq 100$	$COD > 100$
Presence of pathogenic bacteria	no	no	no	yes
Physical and Chemical Factors				
Colour (TCU)	colour < 20	$20 \leq \text{colour} \leq 30$	colour < 30	n/a
Water temperature ($^{\circ}\text{C}$)	temperature < 25	$25 \leq \text{temperature} < 30$	$30 \leq \text{temperature} < 35$	temperature > 35
pH	$6.0 \leq \text{pH} \leq 8.5$	$5.5 < \text{pH} < 6.0$ or $8.5 < \text{pH} < 9.5$	$\text{pH} \leq 5.5$ or $\text{pH} \geq 9.5$	N/A
Total suspended Solids (TSS) (mg/L)	$TSS < 30$	$30 \leq TSS < 60$	$60 \leq TSS < 100$	$TSS > 100$
Conductivity ($\mu\text{S}/\text{cm}$)	conductivity ≤ 250	$250 < \text{conductivity} \leq 500$	$500 < \text{conductivity} \leq 3000$	conductivity > 3000

TCU = True colour unit.

N/A = Not applicable.

In the absence of national (Madagascar) water quality guidelines for the protection of aquatic life or for drinking water quality, guidelines from other jurisdictions were used. Specifically, site water quality results were compared with aquatic life guidelines from Canada (CCME 2003) and the United States (US) (U.S. EPA 2004) and with the drinking water quality guidelines from the World Health Organization (WHO 2004). When Canadian Council of Ministers of the Environment (CCME) and U.S. Environmental Protection Agency (EPA) guidelines for aquatic life differed, the most stringent guideline from both jurisdictions was used to compare water quality data from the site.

Aquatic life guidelines from Canada and the US were selected for this project because the project proponent (Dynatec) is a North American company. As such, there is an expectation from stakeholders that standards in use in Canada and the US should be applicable to this project. The WHO drinking water quality guidelines were selected because they are the most commonly used guidelines

when assessing drinking water quality in countries where national guidelines do not exist.

Caution should be exercised when comparing water and sediment quality conditions for the project with guidelines that have not been derived based on a consideration of local (Madagascar) conditions. Even within jurisdictions where guidelines are generated, it is not uncommon for observed values of some parameters to exceed guidelines, due to site-specific factors such as local climatic, hydrological or geological conditions. This is usually the case, for example, with respect to certain metals (e.g., aluminum, iron and manganese) and nutrients (e.g., total phosphorous) that tend to show elevated concentrations during high runoff periods, in association with suspended solids (i.e., TSS). When total metals are above a guideline, a portion is often associated with suspended particles in the water, and is not necessarily bioavailable.

Natural variability of baseline water and sediment quality conditions commonly results in some parameters being above guideline levels. This is not considered to be of a concern because it is a natural phenomenon and the distribution of species will be adapted to the natural levels present.

2.3.1.3 Seasonal Patterns

To examine the presence, if any, of seasonal differences between the 2004 water quality results, data collected during the dry season were compared with that from the wet season. Insufficient data were available to allow a statistical comparison of differences in results between seasons to be made. As a result, the comparison was qualitative in nature. When a station and parameter were sampled in both the wet and dry seasons, the two results for each parameter were compared and the season with the higher value was noted. Some metals were not comparable due to differences in detection limits. The number of stations with higher values in the wet season and dry season were counted and reviewed for a consistent pattern. The totals were presented for parameters that appeared to have a seasonal pattern.

Results from the two seasons (wet and dry) of sampling in 2004 were also compared by groupings of stations within each area (as shown in Table 9.1-1), when the results of three or more stations could be compared. A qualitative assessment of these grouped results was completed to detect seasonal trends that may occur in different water body types.

2.3.1.4 Spatial Patterns

The 2004 results were assessed for spatial patterns by season. Because insufficient data were available to complete a statistical analysis, results were qualitatively reviewed by grouping of stations by both water body type and basin (as shown in Table 9.1-1 and 9.1-2) within each area. Result values and symbols designating water body groupings were plotted on a map of each area. These maps were visually reviewed for spatial patterns.

Water quality results in the mine area were reviewed for spatial patterns that would indicate influence from the ore bodies. Water quality influences from the ore bodies were identified if results from stations immediately downstream from the ore bodies were greater compared to both:

- results from stations on the same watercourse further downstream from the ore bodies; and
- results from stations from similar types of water bodies, further away from the ore bodies.

2.3.1.5 Comparison to Historical Data

Historical water quality data were collected at sixteen stations between 1996 and 1998 within the mine area (Volume I-9.1, Attachment 1). Water quality data from 2004 were qualitatively compared to historical data at each station for each season. Only data from the same stations and same seasons were compared to each other to reduce the variability that could be introduced by comparing data from all stations for both seasons. The numbers of 2004 results that were within, above or below the range of results collected in 1996 to 1998 were counted and reviewed. If the majority of 2004 values for a given parameter were greater than the historical range of values, an increase in this parameter was qualitatively identified.

A portion of the 2004 data could not be compared to historical data (1996 to 1998) because:

- historical data (prior to 2004) were only collected at the mine site and therefore this analysis could only be completed for stations in the mine area;
- some stations and parameters that were monitored in 2004 were not monitored previously; and
- concentrations of most metals were below detection limits from 1996 1998 and also in the wet season of 2004.

Two sets of data were analyzed to compare historical and 2004 results:

- all stations (by station and by season) within the mine area; and
- only stations immediately downstream of the ore bodies (by station and by season) in the mine area.

Parameters that were analyzed or measured in 2004 that were not included in the 1996 to 1998 data set include DO, turbidity, Total Kjeldahl Nitrogen (TKN), BOD and COD, microbiological parameters and thirteen metals (see Table 9.1-3).

Due to the lower detection limits used for metals analyses in the 2004 dry season, the metals results from the 2004 dry season were more precise compared to the 2004 wet season and historical (1996 to 1998) results.

2.3.2 Sediment Quality Data Analysis

2.3.2.1 Comparison to Guidelines

Sediment quality data collected in 2004 were discussed in terms of particle size, nutrient content, metal content and comparison to sediment quality guidelines or thresholds for each sampling area. In the absence of Malagasy sediment quality guidelines, sediment quality guidelines and thresholds from other jurisdictions were applied. Standards used to assess the sediment quality data included:

- Canadian Sediment Quality Guidelines (CCME 2003); and
- United States National Oceanographic and Atmospheric Association (U.S. NOAA 1999) thresholds.

Because CCME and NOAA sediment quality guidelines are based on toxicity testwork conducted using species found in Canada and the US, the guidelines may not be directly applicable to aquatic life in Madagascar. Therefore, the interpretation of results showing exceedance of a parameter relative to these guidelines should take this factor into consideration.

The values for both sets of guidelines were equal, with the exception of nickel, which is not included in the CCME guidelines. CCME and NOAA have two sets of sediment standards. The NOAA's threshold effect level (TEL) is equivalent to CCME's Interim Sediment Quality Guideline (ISQG) and represents the upper limit in the range of sediment chemical concentrations that is dominated by no-effect results. Sediment quality values within the TEL are not considered to

represent significant hazards to aquatic organisms. The probable effect level (PEL) for both NOAA and CCME represents the lower limit of the range in sediment chemical concentrations that is usually or always associated with adverse biological effects.

2.3.2.2 Spatial Patterns

The sediment quality data collected in 2004 were assessed for spatial patterns. Because insufficient data were available to complete a statistical analysis, results were qualitatively reviewed by station, grouping of stations, and area. Where possible, sediment concentrations from upstream and downstream of the mine site or other potentially disturbed sites were compared. Factors that have a potential to influence sediment quality, such as Total Organic Carbon (TOC) and particle size, were taken into account when reviewing sediment quality for spatial patterns.

3 RESULTS

Water and sediment quality results for the mine site, slurry pipeline corridor, process plant, and tailings facility areas are presented in the following sections.

3.1 MINE SITE

3.1.1 Water Quality

3.1.1.1 General Water Quality Characterization

Water quality data collected at the mine site area during the 2004 wet and dry seasons are presented in Tables 9.1-7 and 9.1-8, respectively. The overall water quality class, based on the Madagascar surface water quality classification system, for each station is also presented in Tables 9.1-7 and 9.1-8.

Water quality in the mine area ranged from acidic (pH of 4.48) to moderately alkaline (pH of 8.19). Dissolved oxygen values were generally below saturation and ranged from 3.8 mg/L to 9.4 mg/L. Water temperatures typically ranged from 18 to 24°C, with the highest temperature (28.4°C) measured in the Mangoro River.

Waters in the mine site area range from very soft (hardness of as low as 3.6 mg/L) to moderately soft (up to 63 mg/L hardness). Lower alkalinity values were observed at seven stations, including QESF-101, QESF-109, the two stations in and downstream of the Torotorofotsy wetlands (QESF-112 and 119) and stations along the Mangoro River. At these seven stations, alkalinity ranged from 9 to 20 mg/L, which suggests that these water bodies may be potentially sensitive to acidification. The alkalinity values observed at all other stations (23 to 56 mg/L) around the mine area suggest low sensitivity to acidification.

Observed ranges in TDS (18 to 184 mg/L) and TSS (<1 to 98 mg/L) within the mine area were considered to be low to moderately low and low to high, respectively.

Nutrient levels were generally low for nitrogen parameters, including nitrate, nitrite, TKN and ammonia, and generally below detection limits for total phosphate. All results for total phosphorus were below detection limits during the dry season and total phosphorus was not analyzed during the wet season. Nutrient status of water bodies are typically determined by their concentration of total phosphorus. Based on Table 6 Attachment 9.1-3, the streams and rivers in the mine area are not eutrophic. However, the detection limit used for total phosphorus (0.04 mg/L) is too high to allow any further determination of nutrient statuses.

Table 9.1-7 Water Quality Results from Mine Site Area (Wet Season 2004)

Parameter	Units	Sampling Location and Date									Guidelines		
											Aquatic Life ⁽¹⁾⁽²⁾		Drinking Water
		QESF 100	QESF 101	QESF 102	QESF 103	QESF 104	QESF 105	QESF 106	QESF 107	QESF 108	EPA		WHO ⁽³⁾
		28-Feb	29-Feb	29-Feb	29-Feb	1-Mar	2-Mar	2-Mar	3-Mar	3-Mar	Acute	Chronic	
Field Parameters													
pH	pH	7.05	5.66	7.34	7	7.35	6.89	7.91	7.37	7.15		6.5 - 9	6.5 - 9
Total dissolved solids	mg/L	-	11	43	37	42	33	58	34	59			
Conductivity	µS/cm	104	24	60	54	61	42	78	48	80			
Turbidity	NTU	2.21	-	-	-	4	7.2	5.4	6.55	6.4			
Temperature	°C	23.6	22.91	20.05	21.85	21.45	22.83	20.95	20.68	21.69			
Dissolved oxygen	mg/L	7.24	3.8	8.79	6.75	8.22	6.84	8.46	7.67	5.61	5	6	5.5 to 6
Dissolved oxygen	%	85.6	44.6	96.8	77.1	93.1	79.4	94.8	85.7	63.8			
Redox potential	mV	56.5	164.4	31.5	72.9	55	63.7	108.3	125.1	17.9			
Conventional Parameters													
pH value at 20 °C	pH	6.8	5.7	6.6	6.8	6.9	6.8	7	7	7		6.5 - 9	6.5 - 9
Total alkalinity as CaCO ₃	mg/L	48	12	38	34	36	26	52	32	46			
Total dissolved solids	mg/L	118	80	62	68	64	66	172	132	184			
Total suspended solids	mg/L	4.5	4.75	3	9.25	3.25	5.25	5	2.25	4.75			
Total hardness as CaCO ₃	mg/L	48	7.7	33	42	41	21	54	36	53			
Conductivity at 25°C	µS/cm	60.9	21.3	55.9	47.2	53.9	36.7	74.1	43.8	70.7			
Nutrients													
Ammonia as N	mg/L	0.1	<0.1	<0.1	<0.1	0.4	0.3	0.2	<0.1	0.2	38.3 ^{(a)(b)}	2.47 ^{(a)(b)}	1.91 ^{(a)(b)}
Nitrate (NO ₃)	mg/L	2	1.6	2.2	0.9	0.7	0.5	2.6	1.7	3.8			13
Nitrite (NO ₂)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1			0.2
Total phosphate (PO ₄)	mg/L	0.3	0.1	0.1	<0.1	0.1	0.2	0.2	<0.1	0.2			
Major Ions													
Bicarbonate (HCO ₃)	mg/L	59	15	46	41	44	32	63	39	56			
Carbonate (CO ₃)	mg/L	-	-	-	-	-	-	-	-	-			
Calcium (Ca)	mg/L	2.6	1.1	5.8	4.1	3.2	2.4	4.8	2.5	2.6			
Chloride (Cl)	mg/L	4.2	4.7	3.1	3.1	3.7	2.6	4.2	2.6	3.7	860	230	
Fluoride (F)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	-0. 1	<0.1	<0.1	<0.1			1.5
Magnesium (Mg)	mg/L	10.1	1.2	4.4	7.8	8	3.7	10.3	7.3	11.3			
Potassium (K)	mg/L	1.5	1.3	2.6	0.8	0.3	0.6	0.7	0.9	1.5			
Sodium (Na)	mg/L	3.1	6.7	<0.1	1.5	0.4	1.7	1.5	<0.1	<0.1			
Sulphate (SO ₄)	mg/L	1.1	6.4	<0.1	2.6	1.4	0.6	0.8	0.8	1.6			
Total Metals													
Aluminum (Al)	mg/L	<0.01	0.18	0.03	0.04	0.01	0.02	0.02	0.02	0.04	0.75	0.087	0.005 to 0.1 ^(d)
Antimony (Sb)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1			0.02
Arsenic (As)	mg/L	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	0.34	0.15	0.005
Barium (Ba)	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05			0.7
Beryllium (Be)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01			
Boron (B)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01			0.5
Cadmium (Cd)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0002 ^{(b)(c)}	0.00004 ^{(b)(c)}	0.000017
Chromium, total (Cr)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.016	0.001	0.001
Chromium (Cr ⁺⁶)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01			
Cobalt (Co)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01			
Copper (Cu)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0013 ^{(b)(c)}	0.0011 ^{(b)(c)}	0.002 ^{(b)(c)}
Iron (Fe)	mg/L	2.1	1.3	0.2	1.5	0.35	1	0.48	0.26	2.2		1	0.3

Table 9.1-7 Water Quality Results from Mine Site Area (Wet Season 2004) (continued)

Parameter	Units	Sampling Location and Date									Guidelines			
											Aquatic Life ⁽¹⁾⁽²⁾			Drinking Water
		QESF 100	QESF 101	QESF 102	QESF 103	QESF 104	QESF 105	QESF 106	QESF 107	QESF 108	EPA		CCME	WHO ⁽³⁾
		28-Feb	29-Feb	29-Feb	29-Feb	1-Mar	2-Mar	2-Mar	3-Mar	3-Mar	Acute	Chronic	Chronic	
Lead (Pb)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.003 ^{(b)(c)}	0.0001 ^{(b)(c)}	0.0001 to 0.0007	0.01
Manganese (Mn)	mg/L	0.14	0.01	0.02	0.07	0.06	0.25	0.04	0.06	0.06				0.4
Mercury (Hg)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.0016	0.0001	0.0001	0.001
Nickel (Ni)	mg/L	0.02	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.01	<0.01	0.055 ^{(b)(c)}	0.006 ^{(b)(c)}	0.025 to 0.15	0.02
Selenium (Se)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01			0.001	0.01
Thorium (Th)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01				
Tin (Sn)	mg/L	0.82	0.51	0.08	0.62	0.14	0.42	0.19	0.1	0.88				
Uranium (U)	mg/L	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2				0.015
Vanadium (V)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01				
Zinc (Zn)	mg/L	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.014 ^{(b)(c)}	0.014 ^{(b)(c)}	0.03	
Biological Parameters														
Total coliforms	CFU/100 ml	1500	1500	930	930	150	1100	1500	460	4600				
Organics														
Oil and grease	mg/L	<0.2	2.2	<0.2	<0.2	0.4	<0.2	0.6	2.6	<0.2				
Madagascar classification ⁽⁴⁾		A	B	A	A	A	A	A	A	A				

Table 9.1-7 Water Quality Results from Mine Site Area (Wet Season 2004) (continued)

Parameter	Units	Sampling Location and Dates								Guidelines			
										Aquatic Life ⁽¹⁾⁽²⁾			Drinking Water
		QESF 109	QESF 109b (duplicate)	QESF 110	QESF 111	QESF 112	QESF 114	QESF 114b (duplicate)	QESF 115	EPA		CCME	WHO ⁽³⁾
		5-Mar	5-Mar	4-Mar	4-Mar	5-Mar	1-Apr	19-Apr	8-Apr	Acute	Chronic	Chronic	
Field Parameters													
pH	pH	6.84	-	7.69	6.91	6.31	6.96	6.64	6.39		6.5 - 9	6.5 - 9	
Total dissolved solids	mg/L	150	-	-	-	-	-	-	-				
Conductivity	µS/cm	22	-	30	86	31	56	57	18				
Turbidity	NTU	2.8	-	4	6.1	3.2	12.3	9.95	14.2				
Temperature	°C	21.1	-	21.6	24.04	22.7	21.84	21.07	23.41				
Dissolved oxygen	mg/L	8.81	-	-	4.73	-	8.67	7.54	7.68	5	6	5.5 to 6	
Dissolved oxygen	%	99.1	-	-	56.3	-	99	84.7	90.2				
Redox potential	mV	174	-	-	17.5	-	16.8	26.4	105.1				
Conventional Parameters													
pH value at 20 °C	pH	6.8	6.6	6.9	6.9	6.2	7.1	7.1	7.3		6.5 - 9	6.5 - 9	
Total alkalinity as CaCO ₃	mg/L	14	14	30	48	20	30	30	7				
Total dissolved solids	mg/L	38	46	56	118	48	72	112	18				
Total suspended solids	mg/L	1.5	3	2	3	2	3	7.5	18				
Total hardness as CaCO ₃	mg/L	13.7	14.2	33	55	20	26	31	3.6				
Conductivity at 25°C	µS/cm	20.1	20.3	41.6	70.9	30	68.9	68.5	24.7				

Table 9.1-7 Water Quality Results from Mine Site Area (Wet Season 2004) (continued)

Parameter	Units	Sampling Location and Dates								Guidelines			
										Aquatic Life ⁽¹⁾⁽²⁾		Drinking Water	
		QESF 109	QESF 109b (duplicate)	QESF 110	QESF 111	QESF 112	QESF 114	QESF 114b (duplicate)	QESF 115	EPA		CCME	WHO ⁽³⁾
		5-Mar	5-Mar	4-Mar	4-Mar	5-Mar	1-Apr	19-Apr	8-Apr	Acute	Chronic	Chronic	
Nutrients													
Ammonia as N	mg/L	0.2	0.5	0.2	<0.1	0.1	<0.1	<0.1	0.2	38.3 ^{(a)(b)}	2.47 ^{(a)(b)}	1.91 ^{(a)(b)}	
Nitrate (NO ₃)	mg/L	1.6	0.5	1.7	<0.1	1.1	0.6	0.4	<0.1			13	50
Nitrite (NO ₂)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1			0.2	0.2
Total phosphate (PO ₄)	mg/L	<0.1	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1				
Major Ions													
Bicarbonate (HCO ₃)	mg/L	17	17	37	59	24	37	37	9				
Carbonate (CO ₃)	mg/L	-	-	-	-	-	-	-	-				
Calcium (Ca)	mg/L	0.2	0.4	2.9	4.9	2.3	0.7	3	0.3				
Chloride (Cl)	mg/L	1.6	1.6	2.6	4.7	2.6	4.7	3.6	1.6	860	230		
Fluoride (F)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1				1.5
Magnesium (Mg)	mg/L	3.2	3.2	6.2	10.4	3.5	6	5.8	0.7				
Potassium (K)	mg/L	0.2	0.4	1.5	0.3	0.6	1.3	1.1	1.2				
Sodium (Na)	mg/L	<0.1	<0.1	<0.1	<0.1	0.7	2.7	2.6	1.7				
Sulphate (SO ₄)	mg/L	1.6	1.1	0.8	2.1	5.4	5.4	0.3	2.2				
Total Metals													
Aluminum (Al)	mg/L	0.03	0.03	0.02	0.02	0.15	0.02	0.04	0.12	0.75	0.087	0.005 to 0.1 ^(d)	
Antimony (Sb)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1				0.02
Arsenic (As)	mg/L	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.34	0.15	0.005	0.01
Barium (Ba)	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05				0.7
Beryllium (Be)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01				
Boron (B)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.01				0.5
Cadmium (Cd)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0002 ^{(b)(c)}	0.00004 ^{(b)(c)}	0.000017	0.003
Chromium total (Cr)	mg/L	0.01	0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.016	0.001	0.001	0.05
Chromium (Cr ⁺⁶)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01				
Cobalt (Co)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01				
Copper (Cu)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0013 ^{(b)(c)}	0.0011 ^{(b)(c)}	0.002 ^{(b)(c)}	2
Iron (Fe)	mg/L	0.09	0.09	0.1	1.4	1.2	2.99	2.87	1.17		1	0.3	
Lead (Pb)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.003 ^{(b)(c)}	0.0001 ^{(b)(c)}	0.0001 to 0.0007	0.01
Manganese (Mn)	mg/L	0.01	0.01	0.01	0.08	<0.01	0.1	0.1	0.02				0.4
Mercury (Hg)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.0016	0.0001	0.0001	0.001
Nickel (Ni)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	<0.01	0.055 ^{(b)(c)}	0.006 ^{(b)(c)}	0.025 to 0.15	0.02
Selenium (Se)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01			0.001	0.01
Thorium (Th)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01				
Tin (Sn)	mg/L	0.04	0.04	0.04	0.56	0.49	1.1	1.05	0.43				
Uranium (U)	mg/L	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2				0.015
Vanadium (V)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01				
Zinc (Zn)	mg/L	<0.01	0.06	0.04	<0.01	0.01	<0.01	<0.01	<0.01	0.014 ^{(b)(c)}	0.014 ^{(b)(c)}	0.03	
Biological Parameters													
Total coliforms	CFU/100 ml	<3	210	-	-	240	4,600	4,600	460				
Organics													
Oil and grease	mg/L	<0.2	<0.2	<0.2	2,580	3,905	7.8	71	<0.2				
Madagascar classification ⁽⁴⁾		A	A	A	B	A	A	A	A				

Table 9.1-7 Water Quality Results from Mine Site Area (Wet Season 2004) (continued)

Parameters	Units	Sampling Location and Dates									Guidelines				
											Aquatic Life ⁽¹⁾⁽²⁾			Drinking Water	
		QESF 116	QESF 117	QESF 118	QESF 119	QESF 120	QESF 121	QESF 122	QESF 150 (field blank)	QESF 160 (field blank)	EPA		CCME	WHO ⁽³⁾	
		31-Mar	31-Mar	1-Apr	7-Apr	8-Apr	8-Apr	18-Apr	5-Mar	1-Apr	Acute	Chronic	Chronic		
Field Parameters															
pH	pH	7.88	8.19	7.33	6.48	6.34	5.78	4.48	6.3	-		6.5 - 9	6.5 - 9		
Total dissolved solids	mg/L	-	-	-	-	-	-	-	1	-					
Conductivity	µS/cm	70	66	70	74	18	18	23	1	-					
Turbidity	NTU	7.98	3.47	5.66	6.2	13.3	17	2.7	0.85	-					
Temperature	°C	19.1	19.03	22.22	21.56	23.6	23.83	21.5	22.5	-					
Dissolved oxygen	mg/L	-	-	6.62	2.04	8.17	8.02	5.32	6.42	-	5	6	5.5 to 6		
Dissolved oxygen	%	-	-	76	23.2	87.4	95	60.2	74.7	-					
Redox potential	mV	35.3	22.4	22.8	-3.7	125.3	160.1	254	214	-					
Conventional Parameters															
pH value at 20°C	pH	8.7	9.2	7	6.5	7.2	7.2	5	6.2	5.7		6.5 - 9	6.5 - 9		
Total alkalinity as CaCO ₃	mg/L	42	37	34	23	8	8	2	12	5					
Total dissolved solids	mg/L	-	56	104	66	34	34	36	164	22					
Total suspended solids	mg/L	-	3.5	1.5	8	16.5	15	8.5	0.5	0.5					
Total hardness as CaCO ₃	mg/L	50	47	32	31	7.2	3.9	7.3	13.2	1.3					
Conductivity at 25°C	µS/cm	94.8	109	84.8	61.6	23.1	23.5	27.8	3	2.88					
Nutrients															
Ammonia as N	mg/L	<0.1	0.2	0.2	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	38.3 ^{(a)(b)}	2.47 ^{(a)(b)}	1.91 ^{(a)(b)}		
Nitrate (NO ₃)	mg/L	<0.1	0.3	<0.1	0.8	0.2	0.2	0.4	<0.1	0.1			13	50	
Nitrite (NO ₂)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1			0.2	0.2	
Total phosphate (PO ₄)	mg/L	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	0.6	<0.1	0.3					
Major Ions															
Bicarbonate (HCO ₃)	mg/L	49	33	41	28	10	10	2	15	6					
Carbonate (CO ₃)	mg/L	1	6	-	-	-	-	-	-	-					
Calcium (Ca)	mg/L	2.3	3.5	6.1	3.4	0.9	0.4	1.1	5.3	0.2					
Chloride (Cl)	mg/L	3.6	4.1	5.2	3.1	2.1	0.5	4.1	1.6	1.6	860	230			
Fluoride (F)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1				1.5	
Magnesium (Mg)	mg/L	10.7	9.3	4	5.5	1.2	0.7	1.1	<0.1	0.2					
Potassium (K)	mg/L	0.8	0.2	1.6	0.5	0.5	1.5	1	0.2	0.3					
Sodium (Na)	mg/L	1.9	2	5.2	1.7	1.9	2	1.7	<0.1	<0.1					
Sulphate (SO ₄)	mg/L	6.7	1.6	1.6	6.7	2.9	2.1	1.3	1.1	1.1					
Total Metals															
Aluminum (Al)	mg/L	0.05	0.02	0.02	0.1	0.1	0.1	0.32	<0.01	0.02	0.75	0.087	0.005 to 0.1 ^(d)		
Antimony (Sb)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1				0.02	
Arsenic (As)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.34	0.15	0.005	0.01	
Barium (Ba)	mg/L	<0.05	<0.05	<0.06	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05				0.7	
Beryllium (Be)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01					
Boron (B)	mg/L	0.02	0.01	0.02	0.02	<0.01	0.01	0.01	<0.01	0.02				0.5	
Cadmium (Cd)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0002 ^{(b)(c)}	0.00004 ^{(b)(c)}	0.000017	0.003	
Chromium, total (Cr)	mg/L	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.016	0.001	0.001	0.05	
Chromium (Cr ⁺⁶)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01					
Cobalt (Co)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01					

Table 9.1-7 Water Quality Results from Mine Site Area (Wet Season 2004) (continued)

Parameters	Units	Sampling Location and Dates									Guidelines			
											Aquatic Life ⁽¹⁾⁽²⁾			Drinking Water
		QESF 116	QESF 117	QESF 118	QESF 119	QESF 120	QESF 121	QESF 122	QESF 150 (field blank)	QESF 160 (field blank)	EPA		CCME	WHO ⁽³⁾
		31-Mar	31-Mar	1-Apr	7-Apr	8-Apr	8-Apr	18-Apr	5-Mar	1-Apr	Acute	Chronic	Chronic	
Copper (Cu)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0013 ^{(b)(c)}	0.0011 ^{(b)(c)}	0.002 ^{(b)(c)}	2
Iron (Fe)	mg/L	0.1	0.05	0.9	12.7	1.17	1.24	2.19	0.06	<0.01		1	0.3	
Lead (Pb)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.003 ^{(b)(c)}	0.0001 ^{(b)(c)}	0.0001 to 0.0007	0.01
Manganese (Mn)	mg/L	0.02	0.01	0.07	0.28	0.03	0.03	0.06	<0.01	<0.01				0.4
Mercury (Hg)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.0016	0.0001	0.0001	0.001
Nickel (Ni)	mg/L	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.055 ^{(b)(c)}	0.006 ^{(b)(c)}	0.025 to 0.15	0.02
Selenium (Se)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01			0.001	0.01
Thorium (Th)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01				
Tin (Sn)	mg/L	0.04	0.02	0.33	4.26	0.43	0.46	0.8	0.03	<0.01				
Uranium (U)	mg/L	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2				0.015
Vanadium (V)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01				
Zinc (Zn)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.08	<0.01	0.014 ^{(b)(c)}	0.014 ^{(b)(c)}	0.03	
Biological Parameters														
Total coliforms	CFU/100 ml	150	43	1100	93	1500	750	1100	460	150				
Organics														
Oil and grease	mg/L	19	32	60	19.8	<0.2	1.4	10	<0.2	<0.2				
Madagascar classification ⁽⁴⁾		A	A	A	C	A	B	C						

Notes: Guidelines are from United States Environment Protection Agency (U.S. EPA.) 2004. National Recommended Water Quality Criteria; CCME (Canadian Council of Ministers of the Environment) Guidelines (2003) and WHO (World Health Organization) 2004.

(1)

Values above (or below, for pH and dissolved oxygen) chronic guidelines are shown in bold.

(2)

Values above acute guidelines are shown in italics.

(3)

Values above WHO guidelines are highlighted.

(4)

Results were compared to classifications values in Table 9.1-6, with the worse class for any given parameter used to assign an overall classification at each station.

(a)

The 1-hour concentration of total ammonia nitrogen (in mg N/L) does not exceed, more than once in every three years on average, the CMC (acute criterion) calculated using the following equation:
CMC = (0.411/1+10 7.204-pH) + (58.4/+10 pH-7.204).

The 30-day average concentration of total ammonia nitrogen (in mg N/L) does not exceed, more than once in every three years on average, the CCC (chronic criterion) calculated using the following equations.
CCC = ((0.577/1+10 7.688-pH) + (2.487/+10 pH-7.688) * MIN (2.85, 1.45 * 10 0.028 * (25-T)).
U.S. EPA (1999).

(b)

When the criteria is a function of pH, hardness or temperature, the number presented in this table is based on pH of 6.9, total hardness of 10 mg/L and a temperature of 28.4. For comparison to guidelines, a criteria was calculated for each result based on the observed pH, hardness and/or temperature at the station.

(c)

The freshwater criterion for this metal is expressed as a function of hardness (mg/L) in the water column. Criteria values for each result were calculated from the following:
CMC (dissolved) = exp{mA [ln(hardness)]+ bA} (CF), or CCC (dissolved) = exp{mC [ln (hardness)]+ bC} (CF) and the parameters specified in Appendix B- Parameters for Calculating Freshwater Dissolved Metals Criteria That Are Hardness-Dependent.

- Not available.

CCC

= Criteria Continuous Concentration (chronic value).

CMC

= Criteria Maximum Concentration (acute value).

Table 9.1-8 Water Quality Results from Mine Site Area (Dry Season 2004)

Parameters	Units	Identification Sample - Sampling Date								Guidelines			
		QESF 100	QESF 101	QESF 102	QESF 103	QESF 104	QESF 104 ^(b) (duplicate)	QESF 105	QESF 106	Aquatic Life ⁽¹⁾⁽²⁾		Drinking Water	
		10-Nov	6-Nov	7-Nov	6-Nov	10-Nov	10-Nov	2-Nov	10-Nov	EPA			CCME
										Acute	Chronic	Chronic	WHO ⁽³⁾
Field Parameters													
pH	pH units	6.77	6.04	6.52	7.02	7.18	-	6.22	7.59		6.5 - 9	6.5 - 9	
Total dissolved solids	mg/L	67	16	55	60	56	-	56	70				
Conductivity	µS/cm	103	25	72	84	77	-	76	96				
Turbidity	UTN	5.6	5.1	3.4	3.4	5.74	-	16.1	3.5				
Temperature	°C	24.56	23.91	17.2	19.98	19.43	-	18.46	19.62				
Dissolved oxygen	mg/L	6.75	5.75	8.2	8.18	9.08	-	6.1	9.42	5	6	5.5 to 6	
Dissolved oxygen	%	81.1	68.1	85.2	90	98.7	-	65.1	102				
Oxydo-reduction potential	mV	-38.6	72.1	31.3	77.8	41.4	-	78.5	61.1				
Conventional Parameters													
pH value at 25°C ⁽⁴⁾	pH units	7.5	6.2	7.1	7.4	8.3	7.6	7.1	7.4		6.5 - 9	6.5 - 9	
Total alkalinity as CaCO ₃	mg/L	46	10	36	42	40	40	36	52				
Total dissolved solids	mg/L	66	36	84	72	54	60	70	72				
Total suspended solids	mg/L	8	2	<1	<1	3	1	8	1				
Total hardness as CaCO ₃	mg/L	46	8.9	27	46	43	43	26	53				
Conductivity at 25°C	µS/cm ⁽⁵⁾	113	25.0	82.9	91.4	87.6	87.1	86.0	111				
Nutrients													
Free and saline ammonia as N	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	38.3 ^{(a)(b)}	2.47 ^{(a)(b)}	1.91 ^{(a)(b)}	
Nitrate (NO ₃)	mg/L	5.2	0.6	0.3	<0.1	6	5	0.5	6.4			13	50
Nitrite (NO ₂)	mg/L	<0.1	<0.01	<0.01	<0.01	<0.1	<0.1	<0.01	<0.1			0.2	0.2
Total Kjeldahl nitrogen as N	mg/L	<0.1	-	-	-	<0.1	<0.1	-	<0.1				
Dissolved organic carbon (DOC)	mg/L	<1	-	-	-	<1	<1	-	<1				
Total phosphorus	mg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.041	<0.04	<0.04				
Total phosphate (PO ₄)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1				
Major Ions													
Bicarbonate (HCO ₃)	mg/L	56	12	44	51	44	49	44	63				
Calcium (Ca)	mg/L	3.1	1.6	5.9	5.7	4.6	4.6	4.4	5.2				
Chloride (Cl)	mg/L	2.5	1	4.5	3.5	4	2.5	3	2.5	860	230		
Fluoride (F)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1				1.5
Magnesium (Mg)	mg/L	9.4	1.2	3.1	7.7	7.6	7.6	3.7	9.7				
Potassium (K)	mg/L	0.5	0.7	1.7	0.4	0.3	0.3	3	0.3				
Sodium (Na)	mg/L	0.8	0.3	4.2	2.8	0.8	0.8	5.8	1.1				
Sulphate (SO ₄)	mg/L	1.3	0.8	0.8	1.8	1.3	1.1	0.3	1.1				
Total Metals													
Aluminum (Al)	mg/L	0.004	0.04	0.04	0.04	0.02	0.02	0.04	0.02	0.75	0.087	0.005 to 0.1 ^(d)	
Antimony (Sb)	mg/L	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006				0.02
Arsenic (As)	mg/L	0.0003	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	0.34	0.15	0.005	0.01
Barium (Ba)	mg/L	0.02	0.008	0.008	0.008	0.006	0.007	0.008	0.01				0.7
Beryllium (Be)	mg/L	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002				
Bismuth (Bi)	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005				
Boron (B)	mg/L	<0.006	0.006	0.006	0.006	<0.006	<0.006	0.006	<0.006				0.5
Cadmium (Cd)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.0002 ^{(b)(c)}	0.00004 ^{(b)(c)}	0.000017	0.003
Chromium, total (Cr)	mg/L	0.007	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	0.009	0.016	0.001	0.001	0.05
Chromium (Cr ⁺⁶)	mg/L	-	-	-	-	-	--	-	-				
Gallium (Ga)	mg/L	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002				

Table 9.1-8 Water Quality Results from Mine Site Area (Dry Season 2004) (continued)

Parameters	Units	Identification Sample - Sampling Date								Guidelines			
		QESF 100	QESF 101	QESF 102	QESF 103	QESF 104	QESF 104 ^(b) (duplicate)	QESF 105	QESF 106	Aquatic Life ⁽¹⁾⁽²⁾			Drinking Water
		10-Nov	6-Nov	7-Nov	6-Nov	10-Nov	10-Nov	2-Nov	10-Nov	EPA		CCME	WHO ⁽³⁾
										Acute	Chronic	Chronic	
Germanium (Ge)	mg/L	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012				
Gold (Au)	mg/L	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004				
Cobalt (Co)	mg/L	0.005	0.001	0.001	0.001	<0.001	<0.001	0.001	<0.001				
Copper (Cu)	mg/L	<0.002	<0.002	<0.002	<0.002	<0.002	0.004	<0.002	0.002	0.0013 ^{(b)(c)}	0.0011 ^{(b)(c)}	0.002 ^{(b)(c)}	2
Indium (In)	mg/L	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004				
Iron (Fe)	mg/L	2.9	1.5	1.5	1.5	0.4	0.35	1.5	0.24		1	0.3	
Lead (Pb)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.003 ^{(b)(c)}	0.0001 ^{(b)(c)}	0.0001 to 0.0007	0.01
Manganese (Mn)	mg/L	0.2	0.03	0.03	0.03	0.06	0.06	0.03	0.03				0.4
Mercury (Hg)	mg/L	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	0.0016	0.0001	0.0001	0.001
Molybdenum (Mo)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			0.073	0.07
Nickel (Ni)	mg/L	0.03	<0.003	<0.003	<0.003	0.003	0.003	<0.003	0.003	0.055 ^{(b)(c)}	0.006 ^{(b)(c)}	0.025 to 0.15	0.02
Selenium (Se)	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0003	<0.0001			0.001	0.01
Silicon (Si)	mg/L	7.1	3.2	3.2	3.2	6.3	6.5	3.2	9.8				
Silver (Ag)	mg/L	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	0.0001 ^{(b)(c)}		0.0001	
Strontium (Sr)	mg/L	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.03				
Thallium (Tl)	mg/L	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009			0.0008	
Tellurium (Te)	mg/L	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012				
Thorium (Th)	mg/L	-	-	-	-	-	-	-	-				
Tin (Sn)	mg/L	0.02	0.34	0.34	0.34	<0.02	<0.02	0.34	0.02				
Titanium (Ti)	mg/L	<0.001	<0.001	<0.001	<0.001	0.002	0.002	<0.001	0.001				
Uranium (U)	mg/L	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004				0.015
Vanadium (V)	mg/L	<0.002	<0.002	<0.002	<0.002	0.002	0.002	<0.002	0.002				
Zinc (Zn)	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	0.009	<0.005	<0.005	0.014 ^{(b)(c)}	0.014 ^{(b)(c)}	0.03	
Zirconium (Zr)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001				
Biological Parameters													
Total coliforms	CFU/100 ml	93	2100	43	1500	43	43	-	460				
Organics													
Oil and grease	mg/L	<0.2	12.4	9.2	8.8	<0.2	<0.2	10.4	<0.2				
Biochemical oxygen demand (BOD)	mg/L	0.6	-	-	-	0.6	0.6	-	0.9				
Chemical oxygen demand (COD)	mg/L	65	-	-	-	17	38	-	11				
Madagascar classification ⁽⁶⁾		C	A	A	A	A	B	A	A				

Table 9.1-8 Water Quality Results from Mine Site Area (Dry Season 2004) (continued)

Parameters	Units	Identification Sample - Sampling Date							Guidelines			
		QESF 109	QESF 110	QESF 111	QESF 112	QESF 113	QESF 114	QESF 115	Aquatic Life ⁽¹⁾⁽²⁾		Drinking Water	
		5-Nov	5-Nov	4-Nov	6-Nov	5-Nov	7-Nov	26-Nov	EPA		CCME	WHO ⁽³⁾
									Acute	Chronic	Chronic	
Field parameters												
pH	pH units	7.3	7.52	6.84	6.34	7.11	6.54	6.1		6.5 - 9	6.5 - 9	
Total dissolved solids	mg/L	68	61	66	45	83	54	14				
Conductivity	µS/cm	93	84	89	63	108	80	20				
Turbidity	UTN	2.3	1.8	5	7.5	4.99	17	100				
Temperature	°C	19.6	19.71	18.63	20.1	17.23	23.52	24.1				
Dissolved oxygen	mg/L	7.71	8.36	7.51	5.1	7.39	6.5	6.72	5	6	5.5 to 6	
Dissolved oxygen	%	84.2	91.5	80.4	56.4	77	76.6	80.1				
Oxydo-reduction potential	mV	75.9	57.7	-16.6	65.2	130.3	36.3	147.8				
Conventional Parameters												
pH value at 25 °C ⁽⁴⁾	pH units	7.6	7.9	7.5	6.8	7.4	7	6.1		6.5 - 9	6.5 - 9	
Total alkalinity as CaCO ₃	mg/L	50	46	48	50	56	32	9				
Total dissolved solids	mg/L	82	90	84	44	84	72	46				
Total suspended solids	mg/L	<1	<1	<1	4	5	8	98				
Total hardness as CaCO ₃	mg/L	55	48	49	34	63	31	7.9				
Conductivity at 25°C	µS/cm ⁽⁵⁾	104	97.0	102	69.9	121	82.8	29.1				
Nutrients												
Free and saline ammonia as N	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	38.3 ^{(a)(b)}	2.47 ^{(a)(b)}	1.91 ^{(a)(b)}	
Nitrate (NO ₃)	mg/L	<0.1	<0.1	0.6	0.2	<0.1	0.5	0.1			13	50
Nitrite (NO ₂)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1			0.2	0.2
Total Kjeldahl nitrogen as N	mg/L	-	-	-	-	-	-	-				
Dissolved organic carbon (DOC)	mg/L	-	-	-	-	-	-	-				
Total phosphorus	mg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	-				
Total phosphate (PO ₄)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1				
Major Ions												
Bicarbonate (HCO ₃)	mg/L	61	56	59	61	68	39	11				
Calcium (Ca)	mg/L	2.3	5.7	4.8	4.9	9.9	2.9	1.5				
Chloride (Cl)	mg/L	1.5	2.5	2	2	3	4.5	2.5	860	230		
Fluoride (F)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1				1.5
Magnesium (Mg)	mg/L	12	8.1	8.9	5.2	9.4	5.8	1				
Potassium (K)	mg/L	0.2	0.3	1.1	1.2	1.5	1.3	1.2				
Sodium (Na)	mg/L	0.2	0.2	2.3	3.3	2.6	5.5	2				
Sulphate (SO ₄)	mg/L	0.6	1.6	1.6	2.4	2.4	3.2	<0.1				
Total Metals												
Aluminum (Al)	mg/L	0.02	0.02	0.03	0.03	0.04	0.04	1.7	0.75	0.087	0.005 to 0.1 ^(d)	
Antimony (Sb)	mg/L	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006				0.02
Arsenic (As)	mg/L	0.0002	<0.0002	0.0004	<0.0002	0.0002	0.0002	<0.0002	0.34	0.15	0.005	0.01
Barium (Ba)	mg/L	0.004	0.01	0.02	0.008	0.02	0.04	0.07				0.7
Beryllium (Be)	mg/L	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002				
Bismuth (Bi)	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005				
Boron (B)	mg/L	<0.006	<0.006	<0.006	<0.006	<0.006	0.009	<0.006				0.5
Cadmium (Cd)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.0002 ^{(b)(c)}	0.00004 ^{(b)(c)}	0.000017	0.003
Chromium, total (Cr)	mg/L	0.02	0.01	<0.003	<0.003	0.01	0.004	0.006	0.016	0.001	0.001	0.05
Chromium (Cr ⁺⁶)	mg/L	-	-	-	-	-	-	-				
Gallium (Ga)	mg/L	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002				

Table 9.1-8 Water Quality Results from Mine Site Area (Dry Season 2004) (continued)

Parameters	Units	Identification Sample - Sampling Date							Guidelines			
		QESF 109	QESF 110	QESF 111	QESF 112	QESF 113	QESF 114	QESF 115	Aquatic Life ⁽¹⁾⁽²⁾		Drinking Water	
		5-Nov	5-Nov	4-Nov	6-Nov	5-Nov	7-Nov	26-Nov	EPA		CCME	WHO ⁽³⁾
									Acute	Chronic	Chronic	
Germanium (Ge)	mg/L	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012				
Gold (Au)	mg/L	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	-				
Cobalt (Co)	mg/L	<0.001	0.001	0.002	0.003	0.001	0.003	0.003				
Copper (Cu)	mg/L	<0.002	0.03	<0.002	<0.002	<0.002	<0.002	<0.002	0.0013 ^{(b)(c)}	0.0011 ^{(b)(c)}	0.002 ^{(b)(c)}	2
Indium (In)	mg/L	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	0.005				
Iron (Fe)	mg/L	0.1	0.07	1.2	1.8	0.23	4.9	4.4		1	0.3	
Lead (Pb)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.003 ^{(b)(c)}	0.0001 ^{(b)(c)}	0.0001 to 0.0007	0.01
Manganese (Mn)	mg/L	0.01	0.01	0.07	0.1	0.02	0.2	0.14				0.4
Mercury (Hg)	mg/L	0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	0.0016	0.0001	0.0001	0.001
Molybdenum (Mo)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			0.073	0.07
Nickel (Ni)	mg/L	0.003	<0.003	0.003	<0.003	<0.003	0.02	0.004	0.055 ^{(b)(c)}	0.006 ^{(b)(c)}	0.025 to 0.15	0.02
Selenium (Se)	mg/L	<0.0001	<0.0001	<0.0001	0.0006	0.0005	<0.0001	<0.0001			0.001	0.01
Silicon (Si)	mg/L	11	13.5	13.9	7.2	13.9	10	7.3				
Silver (Ag)	mg/L	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	0.0001 ^{(b)(c)}		0.0001	
Strontium (Sr)	mg/L	0.01	0.02	0.03	0.02	0.03	0.03	0.02				
Thallium (Tl)	mg/L	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009			0.0008	
Tellurium (Te)	mg/L	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.01				
Thorium (Th)	mg/L	-	-	-	-	-	-	<0.002				
Tin (Sn)	mg/L	0.01	<0.02	0.27	0.41	<0.02	1.1	<0.02				
Titanium (Ti)	mg/L	0.001	0.001	0.002	0.001	0.002	0.002	0.08				
Uranium (U)	mg/L	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004				0.015
Vanadium (V)	mg/L	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.008				
Zinc (Zn)	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.009	0.014 ^{(b)(c)}	0.014 ^{(b)(c)}	0.03	
Zirconium (Zr)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001				
Biological Parameters												
Total coliforms	CFU/100 ml	93	15	1100	93	1100	1100	11000				
Organics												
Oil and grease	mg/L	8.4	7.6	6.8	6.2	8.2	7	1				
Biochemical oxygen demand (BOD)	mg/L	-	-	-	-	-	-	-				
Chemical oxygen demand (COD)	mg/L	-	-	-	-	-	-	-				
Madagascar classification ⁽⁶⁾		A	A	A	A	A	A	C				

Table 9.1-8 Water Quality Results from Mine Site Area (Dry Season 2004) (continued)

Parameters	Units	Identification Sample - Sampling Date							Guidelines			
		QESF 116	QESF 117	QESF 118	QESF 119	QESF 120	QESF 121	QESF 300 (Field Blank)	Aquatic Life ⁽¹⁾⁽²⁾		Drinking Water	
		4-Nov	2-Nov	4-Nov	11-Nov	25-Nov	25-Nov	10-Nov	EPA	CCME	WHO ⁽³⁾	
Acute	Chronic	Chronic										
Field Parameters												
pH	pH units	7.41	7.63	6.81	5.71	6.32	6.93			6.5 - 9	6.5 - 9	
Total dissolved solids	mg/L	63	70	63	31	12	19					
Conductivity	µS/cm	85	96	88	48	19	31					
Turbidity	UTN	5.3	1.63	5.98	4.59	20	22					
Temperature	°C	18.16	18.78	20.19	25.17	27	28.43					
Dissolved oxygen	mg/L	9.62	8.67	6.43	5.61	8.17	8.42		5	6	5.5 to 6	
Dissolved oxygen	%	102	93	71	68.1	102.6	108.4					
Oxydo-reduction potential	mV	129.5	83.6	77.4	67.4	125.8	46.1					
Conventional Parameters												
pH value at 25 °C ⁽⁴⁾	pH units	7	8.5	7.2	6.6	6.5	5.6	5.6		6.5 - 9	6.5 - 9	
Total alkalinity as CaCO ₃	mg/L	46	52	42	16	9	12	4				
Total dissolved solids	mg/L	72	86	72	16	44	56	6				
Total suspended solids	mg/L	1	<1	3	20	26	24	<1				
Total hardness as CaCO ₃	mg/L	47	52	39	19	7.7	8	<0.6				
Conductivity at 25°C	µS/cm ⁽⁵⁾	8.28	108	95.3	47.8	27.1	32.9	2.2				
Nutrients												
Free and saline ammonia as N	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	1.8	<0.1	38.3 ^{(a)(b)}	2.47 ^{(a)(b)}	1.91 ^{(a)(b)}	
Nitrate (NO ₃)	mg/L	0.3	0.3	<0.1	5.2	1.3	2.2	6.3			13	50
Nitrite (NO ₂)	mg/L	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1			0.2	0.2
Total Kjeldahl nitrogen as N	mg/L	-	-	-	-	-	2.4	<0.1				
Dissolved organic carbon (DOC)	mg/L	-	-	-	-	-	<1	<1				
Total phosphorus	mg/L	<0.04	<0.04	<0.04	<0.04	-	-	<0.04				
Total phosphate (PO ₄)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1				
Major Ions												
Bicarbonate (HCO ₃)	mg/L	56	54	51	20	11	15	5				
Calcium (Ca)	mg/L	3.3	4.5	8.2	2.4	2.1	1.7	<0.1				
Chloride (Cl)	mg/L	3	1	4.5	4	2.5	3.5	1.5	860	230		
Fluoride (F)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1				1.5
Magnesium (Mg)	mg/L	9.5	9.9	4.5	3.2	0.6	0.9	<0.1				
Potassium (K)	mg/L	0.5	<0.1	1.1	0.1	1.3	1.5	0.1				
Sodium (Na)	mg/L	6.4	5.6	4.5	0.6	1.4	2.4	0.2				
Sulphate (SO ₄)	mg/L	1.1	0.8	0.3	1.6	<0.1	<0.1	1.6				
Total Metals												
Aluminum (Al)	mg/L	0.04	0.01	0.04	0.06	0.39	0.34	<0.009	0.75	0.087	0.005 to 0.1 ^(d)	
Antimony (Sb)	mg/L	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006				0.02
Arsenic (As)	mg/L	<0.0002	0.0002	0.0002	<0.0002	<0.0002	<0.0002	<0.0002	0.34	0.15	0.005	0.01
Barium (Ba)	mg/L	0.02	0.004	0.05	0.01	0.03	0.04	0.001				0.7
Beryllium (Be)	mg/L	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002				
Bismuth (Bi)	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005				
Boron (B)	mg/L	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006				0.5
Cadmium (Cd)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.0002 ^{(b)(c)}	0.00004 ^{(b)(c)}	0.000017	0.003
Chromium, total (Cr)	mg/L	0.007	0.01	<0.003	0.003	<0.003	<0.003	<0.003	0.016	0.001	0.001	0.05
Chromium (Cr ⁺⁶)	mg/L	-	-	-	-	-	-	-				
Gallium (Ga)	mg/L	<0.002	<0.002	<0.002	<0.002	0.002	<0.002	<0.002				
Germanium (Ge)	mg/L	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012				
Gold (Au)	mg/L	<0.004	<0.004	<0.004	<0.004	-	-	<0.004				

Table 9.1-8 Water Quality Results from Mine Site Area (Dry Season 2004) (continued)

Parameters	Units	Identification Sample - Sampling Date							Guidelines			
		QESF 116	QESF 117	QESF 118	QESF 119	QESF 120	QESF 121	QESF 300 (Field Blank)	Aquatic Life ⁽¹⁾⁽²⁾		Drinking Water	
		4-Nov	2-Nov	4-Nov	11-Nov	25-Nov	25-Nov	10-Nov	EPA		CCME	WHO ⁽³⁾
									Acute	Chronic	Chronic	
Cobalt (Co)	mg/L	<0.001	0.001	0.001	0.002	0.001	0.001	<0.001				
Copper (Cu)	mg/L	<0.002	<0.002	<0.002	<0.002	<0.002	0.004	<0.002	0.0013 ^{(b)(c)}	0.0011 ^{(b)(c)}	0.002 ^{(b)(c)}	2
Indium (In)	mg/L	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004				
Iron (Fe)	mg/L	0.15	0.02	0.45	3.1	1.6	1.9	0.02		1	0.3	
Lead (Pb)	mg/L	<0.01	<0.01	<0.01	<0.01	0.02	0.02	<0.01	0.003 ^{(b)(c)}	0.0001 ^{(b)(c)}	0.0001 to 0.0007	0.01
Manganese (Mn)	mg/L	0.03	0.008	0.05	0.17	0.04	0.04	0.001				0.4
Mercury (Hg)	mg/L	<0.0003	<0.0003	0.0008	<0.0003	0.0003	<0.0003	<0.0003	0.0016	0.0001	0.0001	0.001
Molybdenum (Mo)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001			0.073	0.07
Nickel (Ni)	mg/L	<0.003	<0.003	<0.003	0.005	<0.003	<0.003	<0.003	0.055 ^{(b)(c)}	0.006 ^{(b)(c)}	0.025 to 0.15	0.02
Selenium (Se)	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001			0.001	0.01
Silicon (Si)	mg/L	13.4	14.2	11.1	<0.007	5.8	8.7	<0.007				
Silver (Ag)	mg/L	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	0.0001 ^{(b)(c)}		0.0001	
Strontium (Sr)	mg/L	0.02	0.02	0.1	0.01	0.02	0.02	<0.001				
Thallium (Tl)	mg/L	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009			0.0008	
Tellurium (Te)	mg/L	<0.012	<0.012	<0.012	<0.012	<0.01	<0.01	<0.012				
Thorium (Th)	mg/L	-	-	-	-	<0.002	<0.002	-				
Tin (Sn)	mg/L	0.02	<0.02	0.09	<0.02	<0.02	<0.02	<0.02				
Titanium (Ti)	mg/L	0.003	0.001	0.001	0.001	0.03	0.02	<0.001				
Uranium (U)	mg/L	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004				0.015
Vanadium (V)	mg/L	0.001	<0.002	<0.002	0.004	0.004	0.004	0.002				
Zinc (Zn)	mg/L	<0.005	<0.005	<0.005	<0.005	0.06	0.08	<0.005	0.014 ^{(b)(c)}	0.014 ^{(b)(c)}	0.03	
Zirconium (Zr)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001				
Biological Parameters												
Total coliforms	CFU/100 ml	-	240	2,400	43	1,100	1,100	<3				
Organics												
Oil and grease	mg/L	6.2	8.2	7.6	<0.2	<0.2	1.8	<0.2				
Biochemical oxygen demand (BOD)	mg/L	-	-	-	-	-	0.7	0.4				
Chemical oxygen demand (COD)	mg/L	-	-	-	-	-	38	48				
Madagascar classification ⁽⁶⁾		A	A	A	B	B	B					

Notes:

(1)

Values above (or below, for pH and dissolved oxygen) chronic guidelines are shown in bold.

(2)

Values above acute guidelines are shown in italics.

(3)

Values above WHO guidelines are highlighted.

(4)

pH Value at 21 °C for QESF 119, pH Value at 22 °C for QESF 100, 104, 104 B, 106 and 300 and 5. pH Value at 24 °C for QESF 115, 120 and 121.

(5)

Laboratory conductivity values were reported in mS/m but are reported in µS/cm comparison to dry season.

(6)

Results were compared to classifications values in Table 9.1-6, with the worse class for any given parameter used to assign an overall classification at each station.

(a)

The guideline for ammonia is pH and temperature dependent. The 1-hour concentration of total ammonia nitrogen (in mg N/L) does not exceed, more than once in every three years on average, the EPA CMC (acute criterion) calculated using the following equation:
CMC = (0.411/1+10^{7.204-pH}) + (58.4/+10^{pH-7.204}).

The 30-day average concentration of total ammonia nitrogen (in mg N/L) does not exceed, more than once in every three years on average, the EPA CCC (chronic criterion) calculated using the following equations.
CCC = ((0.577/1+10^{7.688-pH¹}) + (2.487/+10^{pH-7.688}) * MIN (2.85, 1.45 * 10^{0.028 * (25-T)})).
U.S. EPA (1999).

The chronic CCME guideline is based on a lookup table of pH and temperature values.

(b)

When the criteria is a function of pH, hardness or temperature, the number presented in this table is based on pH of 6.9, total hardness of 10 mg/L and a temperature of 28.4. For comparison to guidelines, a criteria was calculated for each result based on the observed pH, hardness and/or temperature at the station.

(c)

The freshwater criterion for this metal is expressed as a function of hardness (mg/L) in the water column. Criteria values for each result were calculated from the following:
CMC (dissolved) = exp{mA [ln(hardness)]+ bA} (CF), or CCC (dissolved) = exp{mC [ln (hardness)]+ bC} (CF) and the parameters specified in Appendix B- Parameters for Calculating Freshwater Dissolved Metals Criteria That Are Hardness-Dependent

(d)

Aluminum guideline is 0.005 mg/L when pH<6.5 or calcium <4 mg/L and 0.1 mg/L when pH=>6.5 and calcium => 4 mg/L.

-

Not available.

CCC

= Criteria Continuous Concentration (chronic value).

CMC

= Criteria Maximum Concentration (acute value).

Observed concentrations for most metals were, in general, low and below detection limits during both seasons. With the exception of aluminum, iron, manganese and tin, concentrations of trace metals during the wet season were below detection limit. Results for aluminum, barium, cobalt, iron, manganese, nickel, silicon, strontium and tin in the dry season were typically above detection limits for stations in the mine area. The observed differences in metals that were above detection limits in wet and dry season appeared to be due to differences in detection limits (Ba, Co and Ni) and parameters analyzed (St and Si). Observed values in the dry season for barium, cobalt and nickel were generally below the detection limits used in the wet season.

While the majority of the results for both the wet and dry seasons were below guidelines, there were several parameters that exceeded aquatic life and drinking water quality guidelines, or both, at one or more stations (Table 9.1-9). However, as discussed previously (Section 2.3.1.2), caution must be exercised when interpreting values that do not meet guidelines because the guidelines used are not locally derived.

Based on the Madagascar classification system, most water bodies in the mine site area were Class A (Tables 9.1-7 and 9.1-8), which indicates the water is suitable for multiples uses. Several stations were classified as B or C, based on results for DO, water temperature, TSS and COD (Table 9.1-9). No stations were classified as excessively contaminated (Class HC) in the mine area.

In general, there were few results above drinking water guidelines. Three parameters were observed to be above drinking guidelines, including arsenic (at QESF-101), lead (at the three stations in the Mangoro River) and nickel (at QESF-100). The detection limits used to cadmium and uranium in the wet season analyses were above drinking water guidelines. Therefore, it is possible that these parameters may have also been above drinking water guidelines during the wet season.

Values of the field parameters, pH and DO were occasionally below guidelines. Values of pH appear to be below aquatic life guidelines more frequently at stations within wetlands channels. Aluminum, chromium and iron had the largest number of observations above aquatic life guidelines for metals. Based on results collected within the mine area, the Mangoro River appeared to have the highest number of parameters with observations above guidelines.

For some metal parameters, results below detection limits could not be compared to guidelines because the method detection limits were greater than the guidelines. For wet season sampling, the detection limits for all metals were

above the lowest guidelines, with the exception of iron, manganese and zinc. In the dry season, detection limits for cadmium, chromium, lead, mercury, silver and thallium were below the lowest guidelines.

Table 9.1-9 Madagascar Classifications and Number of Stations in the Mine Area with Results Above Guidelines

Parameter	Aquatic Life ^(a)		Drinking Water ^(b)		Madagascar Classifications ^(c)	
	Wet Season (Out of 23)	Dry Season (Out of 20)	Wet Season (Out of 23)	Dry Season (Out of 20)	Wet Season (Out of 23)	Dry Season (Out of 20)
Field pH ^(d)	8	7	n/a	n/a	all A	all A
Dissolved oxygen ^(d)	5	3	n/a	n/a	2 B 1 C	all A
Field conductivity	n/a	n/a	n/a	n/a	all A	all A
Water temperature	n/a	n/a	n/a	n/a	all A	3 B
TSS ^(e)	n/a	n/a	n/a	n/a	all A	1 C
BOD ^(f)	n/a	n/a	n/a	n/a	-	All A
COD ^(f)	n/a	n/a	n/a	n/a	-	2 B 1 C
Aluminum	7	7	n/a	n/a	n/a	n/a
Arsenic	1	0	1	0	n/a	n/a
Chromium, total	4	10	0	0	n/a	n/a
Copper	0	3	0	0	n/a	n/a
Iron	16	14	n/a	n/a	n/a	n/a
Lead	0	3	0	3	n/a	n/a
Mercury	0	3	0	0	n/a	n/a
Nickel	0	1	0	1	n/a	n/a
Zinc	2	2	n/a	n/a	n/a	n/a

n/a = not applicable (i.e., no guideline).

- = Parameter not measured.

(a) Aquatic life guidelines are the most stringent of EPA (2004) or CCME (2003) guidelines.

(b) Drinking water guidelines are from WHO (2004).

(c) These classifications are based on the ranges and classifications specified in Table 9.1-6. All results were classified as Type A unless otherwise noted.

(d) The guideline is a lower limit (dissolved oxygen) or a range (pH) and results were below guidelines.

(e) Only 22 stations had results for TSS in the wet season.

(f) Only four stations had results for BOD and COD in the dry season.

3.1.1.2 Seasonal Patterns

Consistent differences in concentrations between wet and dry seasons in 2004 were observed for only a few parameters based on a comparison of data at 20 stations within the mine area. Wet and dry season data were not comparable for most metal parameters, with the exception of aluminum, iron, manganese and tin, due to differences in detection limits. Four parameters appeared to have

consistently higher results in the wet season compared to the dry season, including:

- percent saturation of dissolved oxygen (17 out of 20);
- chloride (18 out of 20); and
- tin (18 out of 20).

Additional seasonal differences in the 2004 data were observed based on the groupings of stations in Table 9.1-10. Due to the lack of data available in the other groupings of stations (n = 3 to 10), additional data would be needed to confirm seasonal differences.

In general, parameters associated with TSS would be expected to be higher in the wet season due to runoff events and parameters associated with groundwater (i.e.; many of the major ions) would be expected to be higher in the dry season, due to dilution effects. However, based on the 2004 results, this pattern was not consistently observed.

Table 9.1-10 Possible Seasonal Patterns by Mine Area Station Groupings

	Higher in the Wet Season	Higher in the Dry Season
Field pH	streams	Mangoro River
Water temperature	wetlands	
Total dissolved solids	wetlands	
Total suspended solids	wetlands	
Total hardness	irrigation channels	
Ammonia		Mangoro River
Nitrate	streams	
Nitrite		streams
Magnesium	irrigation channels	
Potassium	wetlands	
Sodium	wetlands	
Sulphate	wetlands irrigation channels	
Oil and grease	wetlands	streams
Total coliforms	wetlands	

Seasonal patterns were noted in the historical data for some parameters from the mine area, including conventional parameters, major ions and zinc, based on the

1996 to 1998 historical data (see Volume I-9.1, Attachment 1). The conventional parameters and major ions, with the exception of chloride, were observed at higher concentrations in the dry season compared to the wet season in historical data. The opposite pattern was noted for chloride and zinc. While the chloride and pH results for the 2004 seasonal assessment within the mine area were consistent with the historically observed patterns, the other historically observed patterns were not observed in the 2004 data. This is likely due, in part, to the lack of comparable seasonal data (i.e., none of the observed trends can be statistically verified) and the change in the detection limits for metals.

3.1.1.3 Spatial Patterns

There were no obvious trends in parameter concentrations related to the ore bodies in the 2004 data, with the exception of magnesium and chromium in the dry season. These two parameters appeared to be:

- higher at stations immediately downstream of the ore bodies compared to results from stations in the same grouping; and
- lower at stations that were further downstream from the ore bodies (i.e., values at the upstream station of QESF-100 were greater than values at the downstream station QESF-114 on the Sahamarirana River) along the same watercourse or in the same basin.

Due to the higher detection limits applied to metals parameters in the wet season, the presence or absence of a spatial gradient related to the ore bodies could not be determined.

Other potential spatial patterns observed in the 2004 data for stations within the mine area for both seasons, unless otherwise specified, included:

- lower field pH values at stations in wetlands and larger watercourses (2 to 6 m) compared to other stations in the dry season;
- stations with lower field pH appeared to have higher concentration of aluminum;
- higher concentrations of TSS in the Mangoro River and Torotorofotsy wetlands compared to other stations in the dry season;
- higher concentrations of aluminum in the Mangoro River and Torotorofotsy wetlands compared to other stations;
- lower concentrations of calcium, magnesium, bicarbonate, total hardness, total alkalinity, silicon and TDS in the Mangoro River compared to other stations;

- lower concentrations of calcium, magnesium, bicarbonate, total hardness, total alkalinity and TDS in the Torotorofotsy wetlands in the dry season;
- lower sulphate concentrations in the Mangoro River compared to other stations in the dry season; and
- higher iron, manganese and tin concentrations in Sahhamarirana River (QESF-100 and 114) and Torotorofotsy wetlands.

The Mangoro River and Torotorofotsy wetlands appear to have substantially different water quality compared to other water bodies monitored in the mine area. The observed higher aluminum values in these two water bodies are likely due to higher TSS values because aluminum is often associated with particulates. The more acidic conditions, as indicated by the lower pH values observed in these two water bodies, may also be extracting more aluminum from particulates that have settled out. The lower levels of major ions and related parameters (i.e., TDS, hardness and alkalinity) observed in these two water bodies may indicate lower proportion of groundwater inflow to these water bodies compared to other locations sampled. Higher levels of major ions, TDS, hardness and alkalinity are often observed in groundwater.

Additional data would be needed to confirm the statistical significance of these observed spatial patterns.

3.1.1.4 Temporal Trends

The majority of the 2004 water quality results from stations at the mine area appeared to either be within or less than historical values for non-metal parameters. Due to detection limits, the only metals that were typically comparable between time periods were iron and manganese. Magnesium and iron appeared to have higher values in 2004 compared to the 1996 to 1998 data. These two parameters had the greatest number of 2004 values above historical values based on a comparison of wet and dry season data at each station. This observation was consistent whether data were compared from all stations in the mine area or only from stations closest to the ore bodies. Based on the available data, the statistical significance of the observed differences could not be established.

3.1.2 Sediment Quality

3.1.2.1 Sediment Quality Characterization and Comparison to Guidelines

The sediment quality results from the four stations sampled in the mine area in 2004 are presented in Table 9.1-11. For stations QESF-101 and 104, more than 50% of the sample was made up of fines (silt + clay) compared to station QESF-106 and station QESF-121, on the Mangoro River, which contained more than 50% sands and gravels. The results of carbon and nitrogen sediment parameters were generally higher at stations QESF-101 and 104 and available phosphorus was greatest at the Mangoro River station (8.5 mg/kg).

Sediment quality results for copper (at QESF-104) and nickel (all stations) were above the Canadian Interim Sediment Quality Guideline (ISQG) and the NOAA Threshold Effect Level (TEL) threshold, respectively. Nickel sediment was also above the NOAA Probable Effect Level (PEL) threshold at all stations, with the exception of QESF-121. All other sediment quality parameters were below CCME guidelines and NOAA thresholds. The results of the duplicate samples from Station QESF-104 are substantially different which is likely due to the difference in particle size. The sample from QESF-104 (sample b) with higher metals and nutrients results contained more fine sediments.

Table 9.1-11 Sediment Quality Results from Mine Area (2004)

Parameters	Units	Identification Sample - Sampling Date					Sediment Quality Guidelines ⁽¹⁾	
		QESF 100	QESF 104	QESF 104b (duplicate)	QESF 106	QESF 121	ISQG ⁽²⁾	PEL ⁽³⁾
		10/11/2004	11/11/2004	11/11/2004	10/11/2004	25/11/2004		
Nutrients								
Nitrogen (N)	%	0.13	0.08	0.13	0.06	0.1		
Total oxidisable carbon (C) (by calculation)	%	5.64	2.16	10.5	1.24	1.1		
Carbonate as CO ₃	%	1.25	0.17	0.3	0.2	< 0.05		
Total carbon (C)	%	5.89	2.19	10.6	1.28	1.1		
Available phosphorous (P)	mg/kg	1.5	4	6.5	7.5	8.5		
Total metals								
Aluminum (Al)	%	1.34	1.39	5.20	1.09	3.48		
Antimony (Sb)	mg/kg	<2	<2	<2	<2	<2		
Arsenic (As)	mg/kg	<4	<4	<4	<4	<4	5.9	17
Barium (Ba)	mg/kg	15	25	46	19.5	148		
Beryllium (Be)	mg/kg	<0.4	<0.4	<0.4	<0.4	<0.4		
Boron (B)	mg/kg	<1.2	<1.2	<1.2	<1.2	<1.2		
Cadmium (Cd)	mg/kg	0.21	0.23	<0.2	<0.2	<0.2	0.6	3.5
Cobalt (Co)	mg/kg	97	35	87	17	10		

Table 9.1-11 Sediment Quality Results from Mine Area (2004) (continued)

Parameters	Units	Identification Sample - Sampling Date					Sediment Quality Guidelines ⁽¹⁾	
		QESF 100	QESF 104	QESF 104b (duplicate)	QESF 106	QESF 121	ISQG ⁽²⁾	PEL ⁽³⁾
		10/11/2004	11/11/2004	11/11/2004	10/11/2004	25/11/2004		
Copper (Cu)	mg/kg	34	29	76	12.3	8.3	35.7	197
Iron (Fe)	%	12.60	2.60	6.66	1.58	1.85		
Lead (Pb)	mg/kg	<2	<2	<2	<2	6.4	35	91.3
Manganese (Mn)	mg/kg	733	1,032	1,571	192	191		
Mercury (Hg)	mg/kg	<2	<2	<2	<2	<2	0.17	0.486
Nickel (Ni)	mg/kg	2740	154	321	127	22	18	35.9
Selenium (Se)	mg/kg	<6	<6	<6	<6	<6		
Thallium (Tl)	mg/kg	<2	<2	<2	<2	<2		
Thorium (Th)	mg/kg	0.59	<0.4	<0.4	<0.4	3.6		
Tin (Sn)	mg/kg	<4	<4	<4	<4	<4		
Uranium (U)	mg/kg	<0.8	<0.8	<0.8	<0.8	<0.8		
Vanadium (V)	mg/kg	94	84	218	46	40		
Zinc (Zn)	mg/kg	103	< 1	2	< 1	3.4	123	315
Grain size								
Cobbles (100 - 20) mm	%	0	0	0	0	0		
Gravels (20 - 2) mm	%	0	23	12	5	0		
Coarse sand (2 - 0.2) mm	%	5	10	5	76	16		
Fine sand (0.2 - 0.02) mm	%	17	14	30	8	41		
Silt (0.02 mm - 2 µ)	%	45	35	39	8	24		
Clay (2 - 1) µ	%	33	18	14	3	19		

⁽¹⁾ Sediment Quality Guidelines are from CCME (Canadian Council of Ministers of the Environment) Guidelines (2003), with the exception of nickel which is from the United States National Oceanographic and Atmospheric Association (NOAA) (1999).

⁽²⁾ Values above the Interim Sediment Quality Guideline (or Threshold Effect Level for nickel) are shown in bold.

⁽³⁾ Values above the Probable Effect Level (PEL) are shown in italics.

3.1.2.2 Spatial Patterns

No clear spatial trend in the sediment quality data collected at the mine area was observed. Station QESF-100, which is immediately downstream of one of the ore bodies, appeared to have higher concentrations of metals (i.e., iron, cobalt, nickel, thorium and zinc), but the statistical significance of this pattern could not be tested based on available data.

3.1.3 Summary

3.1.3.1 Water Quality

Based on 2004 pH measurements, the water bodies in the mine area ranged from acidic to moderately alkaline. Dissolved oxygen values were generally below

saturation. Water temperatures were measured as low as 17.2°C at station QESF-102 and as high as 28.4°C in the Mangoro River, but typically ranged from 18 to 24°C.

The hardness of the water ranged from very soft to moderately soft. Based on observed alkalinity results, some water bodies appeared to be sensitive to acidification. Nutrient levels were generally low for nitrogen parameters, including nitrate, nitrite, TKN and ammonia, and generally below detection limits for total phosphate.

Observed concentrations for many metals were below detection limits. Metal results for the wet season were generally below detection limits used in the wet season with the exception of aluminum, iron, manganese and tin. Results for aluminum, barium, cobalt, iron, manganese, nickel, silicon, strontium and tin in the dry season were typically above detection limits used in the dry season for stations in the mine area.

Three parameters were above drinking guidelines, including arsenic, lead and nickel in the mine area. In terms of field parameters, pH and dissolved oxygen values were occasionally below aquatic life guidelines. Results for nine metals (aluminum, arsenic, chromium, copper, iron, lead, mercury, nickel and zinc) were above aquatic life guidelines.

Clear seasonal and spatial patterns in water quality were not observed in the mine area, with the exception of the following parameters and locations. Levels of percent saturation of dissolved oxygen, chloride and tin appear to be greater in the wet season compared to the dry season at stations within the mine area. In the dry season, magnesium and chromium appeared to be influenced by the ore bodies because results were:

- higher at stations immediately downstream of the ore bodies compared to results from stations in the same grouping further from the ore bodies; and/or
- lower at stations that were further downstream from the ore bodies along the same watercourse.

The Mangoro River and Torotorofotsy wetlands appear to have substantially different water quality compared to other stations in the mine area. The lower levels of major ions and related parameters (i.e., TDS, hardness and alkalinity) observed in these two water bodies may indicate lower proportion of groundwater inflow to these water bodies compared to other locations sampled.

The observed higher aluminum values in these two water bodies are likely due to higher TSS values because aluminum is often associated with particulates.

The majority of the 2004 water quality results from stations at the mine area appeared to either be within or less than historical values for most parameters. Magnesium and iron appeared to have higher values in 2004 compared to the 1996 to 1998 data for both wet and dry seasons. This observation was consistent whether data were compared from all stations in the mine area or only from stations closest to the ore bodies.

3.1.3.2 Sediment Quality

Sediment quality results from four stations sampled in the mine area ranged from predominantly fines to predominantly coarse material, which is likely the cause of the observed wide range in sediment nutrient levels.

Results for copper and nickel (all stations) were above the Canadian ISQGs and the NOAA Threshold Effect Level (TEL) threshold, respectively. Nickel sediment was also above the NOAA PEL threshold at four stations. All other sediment quality parameters were below CCME guidelines and NOAA thresholds.

3.2 SLURRY PIPELINE

Field measurements were taken at 12 watercourse stations along the proposed slurry pipeline route (Table 9.1-12). The Madagascar classification results are also shown in Table 9.1-12. The watercourses ranged from slightly acidic (pH of 6.2) to slightly alkaline (pH of 7.6). Temperature values ranged from 17.5 to 27°C and dissolved oxygen results ranged from 6.4 to 8.3.

Based on the Madagascar classification system, five watercourses were classified as Class A, which indicates that these watercourses are suitable for multiple uses, including swimming. Seven of the watercourses were classified as Class B, which indicates that although the water is suitable for non-contact recreation, it may not be suitable for swimming. All results were within aquatic life guidelines for pH (6.5 to 9) and dissolved oxygen (minimum of 6 mg/L).

Table 9.1-12 Water Quality Results from Slurry Pipeline Route

Site	Flow Conditions	Approximate Wetted Width (m)	pH	TDS (ppm)	Temperature (°C)	Dissolved Oxygen (mg/L)	Madagascar Classification
003+500	low flow	5 -10	7.4	65	17.5	-	A
007+500	low flow	<5	6.68	0.06	23.5	6.9	A
012+100	low flow	5 -10	6.2	0	27.0	-	B
052+500	high flow	5 -10	7.1	0	26	7.3	B
060+100	high flow	10 -20	7.2	0	23.5	6.5	A
107+000	low flow	-	7.6	26	-	8	A
146+000	low flow	>50	7.83	0.06	26	7.9	B
157+700	low flow	5 -10	7.25	0.06	25	7.5	B
175+300	low flow	<5	7.1	0.08	27	6.4	B
179+300	low flow	150	7.4	33	29.5	7.5	B
E3 005+150	low flow	-	6.9	-	-	8.3	B
E3 011+950	low flow	-	-	23	-	6.8	A

E3 Denotes sites that were sampled along an alternative pipeline route.

- = No data.

3.3 PROCESS PLANT

3.3.1 Water Quality

3.3.1.1 Water Quality Characterization and Comparison to Guidelines

Water quality data collected at the process plant site area in the wet and dry seasons in 2004 are presented in Tables 9.1-13 and 9.1-14, respectively. The overall water quality class, based on the Madagascar classification system, for each station is also presented in Tables 9.1-13 and 9.1-14.

Based on pH measurements from the process plant area, the water bodies range from acidic (pH of 3.73) to almost neutral (pH of 7.3). Dissolved oxygen measurements were generally at or below saturation and ranged from 0.2 mg/L at station QESF-223 (pond) to 8 mg/L in the Ivondro River. Water temperatures were relatively high for stations around the process plant area in the both wet and dry seasons (25.6 to 32.2°C).

The hardness of the water at most stations was characterized as very soft. However, hardness values ranged from very soft at station QESF-217 (3.4 mg/L) located in a pond to moderately soft in the Pangalanes Canal (67 mg/L). A few water bodies around the process plant area appeared to be potentially sensitive to

acidification based on observed alkalinity values of less than 20 mg/L. Results with alkalinity values below 20 mg/L included stations from the following groups:

- the Ivondro River and tributary to Ivondro River (QESF-225 to 228); and
- ponds (QESF-208, 212, 217, 218, 223 and 224).

The alkalinity values observed at the remaining stations in the process plant area were greater than 20 mg/L, which indicated that these water bodies are likely less sensitive to acidification.

Observed ranges in TDS (16 to 190 mg/L) and TSS (<1 to 137 mg/L) within the process plant area were considered to be low to moderately low and low to high, respectively.

Nutrient levels were generally low for nitrogen parameters, including nitrate, nitrite, TKN and ammonia, and generally below detection limits for total phosphate. All results for total phosphorus were below detection limits during the dry season and total phosphorus was not analyzed during the wet season. Nutrient status of water bodies are typically determined by their concentration of total phosphorus. Based on Table 6 of Attachment 9.1-3, the streams and rivers in the process plant area are not eutrophic. However, the detection limit used for total phosphorus (0.04 mg/L) is too high to allow any further determination of the nutrient status of waterbodies within the process plant area.

Observed concentrations for many metals were below detection limits. The only metals results that were generally above detection limits in the wet season were aluminum, boron, iron and manganese. Dry season results for aluminum, arsenic, barium, iron, manganese, silicon, strontium, titanium, vanadium and zinc were typically above detection limits for stations in the process plant area. Most of the additional parameters above detection limits in the dry season are due to either lower detection limits (As, Ba and V) in the dry season or the parameter was not analyzed in the wet season (Si, Ti and St). Observed values in the dry season for arsenic, barium, and vanadium were generally below the detection limits used in the wet season.

Elevated total coliforms levels were observed in different water bodies during the wet and dry seasons. Stations QESF-225 and QESF-223 had the highest total coliform results of 11000 and 4600 colony forming units (CFU)/100 ml, respectively in the wet season. In the dry season, the highest total coliform results were also 11000 and 4600 CFU/100 ml, but from samples collected at stations QESF-231 and QESF230, respectively. Possible sources of these high values include domestic sewage, livestock, or wildlife.

Table 9.1-13 Water Quality Results from Process Plant Area (Wet Season 2004)

Parameters	Units	Sample Station-Sample Collection Date												Guidelines				
														Aquatic Life ⁽¹⁾			Drinking Water	
		QESF 205	QESF-205 (duplicate)	QESF 206	QESF 208	QESF 212	QESF 217	QESF 218	QESF 219	QESF 220	QESF 223	QESF 224	QESF 225	EPA		CCME	WHO ⁽³⁾	
		10-Mar	10-Mar	10-Mar	10-Mar	12-Mar	14-Mar	14-Mar	14-Mar	14-Mar	15-Apr	15-Apr	16-Apr	Acute	Chronic	Chronic		
Field Parameters																		
pH	pH units	6.72	6.3	6.72	7.07	7.16	6.65	6.88	7.16	7.3	3.73	5.96	5.97		6.5 - 9	6.5 - 9		
Total dissolved solids	mg/L	73	85	45	22	29	17	22	44	145	91	26	22					
Conductivity	µS/cm	122	137	75	46	48	30	36	78	239	152	43	35					
Turbidity	NTU	22.6	-	10.59	3.23	1.95	1.51	3.6	6.8	6.9	12.4	12	36					
Temperature	°C	28.4	27.51	28.86	30.28	29.46	31.02	29.66	32.19	28.88	29.11	28.52	26.46					
Dissolved oxygen	mg/L	25.3 ⁽²⁾	22.6 ⁽²⁾	3.31	7.03	6.74	6.27	6.1	5.38	4.31	0.2	3.58	4.6	5	6	5.5 to 6		
Dissolved oxygen	%	33.1 ⁽²⁾	28.7 ⁽²⁾	43	94.1	90.2	86.3	81.3	74	55.9	2.6	44.6	57.2					
Redox potential	mV	35.9	32.6	29.9	142	86.6	104	92.7	56.3	51.1	112	73.8	113.9					
Conventional Parameters																		
pH value at 20°C ⁽⁴⁾	pH units	6.8	-	7.2	6.2	6.5	6.2	6.6	7.4	10.5	6.3	6.8	6.5		6.5 - 9	6.5 - 9		
Total alkalinity as CaCO ₃	mg/L	49	-	24	3	3	3	9	25	49	32	10	8					
Total dissolved solids	mg/L	186	186	230	82	98	34	102	88	190	106	78	34					
Total suspended solids	mg/L	14.5	14.5	6.5	6	1	10.5	5.5	8.5	15	29	6	137					
Total hardness as CaCO ₃	mg/L	51	-	26	5.9	3.6	3.4	5.6	26	51	35	9.6	9.9					
Conductivity at 25°C	µS/cm	163	-	80.5	43.6	55	31.5	37.8	73.4	188	106.1	39.7	37.1					
Nutrients																		
Ammonia as N	mg/L	0.2	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	38.3 ^{(a)(b)}	2.47 ^{(a)(b)}	1.91 ^{(a)(b)}		
Nitrate (NO ₃)	mg/L	0.5	-	0.8	0.5	0.3	0.3	0.2	0.3	<0.1	0.4	<0.1	<0.1			13	50	
Nitrite (NO ₂)	mg/L	<0.1	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1			0.2	0.2	
Total phosphate (PO ₄)	mg/L	<0.1	-	<0.1	0.4	<0.1	<0.1	<0.1	0.2	0.2	<0.1	<0.1	<0.1					
Major Ions																		
Bicarbonate (HCO ₃)	mg/L	60	-	29	4	4	4	11	30	43	39	12	10					
Carbonate (CO ₃)	mg/L	-	-	-	-	-	-	-	-	8	-	-	-					
Calcium (Ca)	mg/L	13.9	-	7.8	1.2	0.6	0.7	1.4	6.7	13.8	7.8	1.7	1.5					
Chloride (Cl)	mg/L	10.9	-	6.2	7.8	10.4	6.7	8.3	6.7	18.6	10.4	6.7	5.7	860	230			
Fluoride (F)	mg/L	<0.1	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1				1.5	
Magnesium (Mg)	mg/L	3.9	-	1.5	0.7	0.5	0.4	0.5	2.2	3.9	3.7	1.3	1.5					
Potassium (K)	mg/L	2.1	-	0.3	0.3	2.4	<0.1	<0.1	0.7	3.8	4	0.5	0.6					
Sodium (Na)	mg/L	9.3	-	3.6	4.1	5.6	3.4	3.6	4.2	13.5	6.6	3.9	3.4					
Sulphate (SO ₄)	mg/L	2.9	-	3.5	1.4	2.2	3.4	3.2	6.7	6.9	<0.1	6.9	3.4					
Total Metals																		
Aluminum (Al)	mg/L	0.1	-	0.39	0.12	0.09	0.05	0.1	0.08	0.08	0.06	0.06	0.77	0.75	0.087	0.005 to 0.1 ^(d)		
Antimony (Sb)	mg/L	<0.1	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1				0.02	
Arsenic (As)	mg/L	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.34	0.15	0.005	0.01	
Barium (Ba)	mg/L	<0.05	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05				0.7	
Beryllium (Be)	mg/L	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01					
Boron (B)	mg/L	0.02	-	0.01	0.01	<0.01	0.01	<0.01	0.02	0.04	0.06	0.04	0.01				0.5	
Cadmium (Cd)	mg/L	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0002 ^{(b)(c)}	0.00004 ^{(b)(c)}	0.000017	0.003	
Chromium, total (Cr)	mg/L	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.016	0.001	0.001	0.05	
Chromium (Cr ⁺⁶)	mg/L	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01					
Cobalt (Co)	mg/L	<0.01	-	<0.01	<0.1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01					
Copper (Cu)	mg/L	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0013 ^{(b)(c)}	0.0011 ^{(b)(c)}	0.002 ^{(b)(c)}	2	
Iron (Fe)	mg/L	0.74	-	0.72	0.99	0.05	0.34	1	1.9	1.6	14.5	5.17	5.7		1	0.3		

Table 9.1-13 Water Quality Results from Process Plant Area (Wet Season 2004) (continued)

Parameters	Units	Sample Station-Sample Collection Date												Guidelines			
														Aquatic Life ⁽¹⁾			Drinking Water
		QESF 205	QESF-205 (duplicate)	QESF 206	QESF 208	QESF 212	QESF 217	QESF 218	QESF 219	QESF 220	QESF 223	QESF 224	QESF 225	EPA		CCME	WHO ⁽³⁾
		10-Mar	10-Mar	10-Mar	10-Mar	12-Mar	14-Mar	14-Mar	14-Mar	14-Mar	15-Apr	15-Apr	16-Apr	Acute	Chronic	Chronic	
Lead (Pb)	mg/L	<0.1	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.003 ^{(b)(c)}	0.0001 ^{(b)(c)}	0.0001 to 0.0007	0.01
Manganese (Mn)	mg/L	0.07	-	0.03	0.01	<0.01	<0.01	0.02	0.01	0.07	0.47	0.06	0.25				0.4
Mercury (Hg)	mg/L	<0.001	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.0016	0.0001	0.0001	0.001
Nickel (Ni)	mg/L	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.055 ^{(b)(c)}	0.006 ^{(b)(c)}	0.025 to 0.15	0.02
Selenium (Se)	mg/L	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01			0.001	0.01
Thorium (Th)	mg/L	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01				
Tin (Sn)	mg/L	0.27	-	0.26	0.36	0.02	0.13	0.37	0.73	0.6	5.08	1.89	2.06				
Uranium (U)	mg/L	<0.2	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2				0.015
Vanadium (V)	mg/L	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01				
Zinc (Zn)	mg/L	<0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	0.014 ^{(b)(c)}	0.014 ^{(b)(c)}	0.03	
Biological Parameters																	
Total coliforms	CFU/100ml	1,100	1,100	930	240	1,100	1,500	150	1,100	1,500	4,600	2,400	11,000				
Organics																	
Oil and grease	mg/L	<0.2	-	<0.2	19.8	16	16.6	6.4	5	<0.7	7.8	11.8	3.6				
Madagascar classification ⁽⁵⁾		B	B	B	C	B	C	B	C	B	HC	B	HC				

Notes: Guidelines are from United States Environment Protection Agency (U.S. EPA) 2004. National Recommended Water Quality Criteria; CCME (Canadian Council of Ministers of the Environment) Guidelines (2003) and WHO (World Health Organization) 2004.

⁽¹⁾ Values above (or below, for pH and dissolved oxygen) chronic guidelines are shown in bold and values above acute guidelines are shown in italics.

⁽²⁾ Results not considered valid through QA/QC review.

⁽³⁾ Values above WHO guidelines are highlighted.

⁽⁴⁾ pH Value at 21 °C for QESF 119, pH Value at 22 °C for QESF 100, 104, 104 B, 106 and 300 and pH Value at 24 °C for QESF 115, 120 and 121.

⁽⁵⁾ Results were compared to classifications values in Table 9.1-6, with the worse class for any given parameter used to assign an overall classification at each station.

⁽⁶⁾ The 1-hour concentration of total ammonia nitrogen (in mg N/L) does not exceed, more than once in every three years on average, the CMC (acute criterion) calculated using the following equation:

^(a) CMC= (0.411/1+10 7.204-pH) + (58.4/+10 pH-7.204).
The 30-day average concentration of total ammonia nitrogen (in mg N/L) does not exceed, more than once in every three years on average, the CCC (chronic criterion) calculated using the following equations.
CCC = ((0.577/1+10 7.688-pH) + (2.487/+10 pH-7.688) * MIN (2.85, 1.45 * 10 0.028 * (25-T))).
U.S. EPA (1999).

^(b) When the criteria is a function of pH, hardness or temperature, the number presented in this table is based on pH of 6.9, total hardness of 10 mg/L and a temperature of 28.4. For comparison to guidelines, a criteria was calculated for each result based on the observed pH, hardness and/or temperature at the station.

^(c) The freshwater criterion for this metal is expressed as a function of hardness (mg/L) in the water column. Criteria values for each result were calculated from the following:
CMC (dissolved) = exp{mA [ln(hardness)]+ bA} (CF), or CCC (dissolved) = exp{mC [ln (hardness)]+ bC} (CF) and the parameters specified in Appendix B- Parameters for Calculating Freshwater Dissolved Metals Criteria That Are Hardness-Dependent.

- Not available.

CCC = Criteria Continuous Concentration (chronic value).

CMC = Criteria Maximum Concentration (acute value).

Table 9.1-14 Water Quality Results from Process Plant Area (Dry Season 2004)

Parameters	Units	Identification Sample – Sampling Date										Guidelines			
												Aquatic Life ⁽¹⁾⁽²⁾			Drinking Water
		QESF 223	QESF 224	QESF 225	QESF 226	QESF 227	QESF 228	QESF 230	QESF 231	QESF 232	QESF 233	EPA		CCME	WHO ⁽³⁾
		07/11/2004	16/11/2004	14/11/2004	28/11/2004	28/11/2004	28/11/2004	17/11/2004	18/11/2004	27/11/2004	29/11/2004	Acute	Chronic	Chronic	
Field Parameters															
pH	pH units	-	5.59	5.92	7.28	7.21	7.05	5.89	6.33	7.24	6.94		6.5 - 9	6.5 - 9	
Total dissolved solids	mg/L	-	29	28	29	29	29	63	83	129	13				
Conductivity	µS/cm	-	49	46	48	47	47	100	129	215	218				
Turbidity	UTN	-	8.37	170	2.9	2.8	2.8	17.7	7.74	28	26				
Temperature	°C	-	29.1	27.95	28.98	28.4	28.52	27.05	25.56	29.44	29.56				
Dissolved oxygen	mg/L	-	4.75	4.15	7.91	8.02	7.92	1.25	1.95	7.04	7.34	5	6	5.5 to 6	
Dissolved oxygen	%	-	61.7	52.9	102.8	103.1	102.1	15.7	23.9	92.3	96.3				
Oxydo-reduction potential	mV	-	68	54.6	54.3	73.8	54.7	61.3	29.9	75.4	81				
Conventional Parameters															
pH value at 25°C ⁽⁴⁾	pH units	7	6.8	6.7	7.1	7.2	7	7.2	7.3	6.8	7.1		6.5 - 9	6.5 - 9	
Total alkalinity as CaCO ₃	mg/L	10	14	12	17	17	18	40	40	60	62				
Total dissolved solids	mg/L	38	50	16	62	58	52	74	90	150	136				
Total suspended solids	mg/L	12	18	73	4	<2	<2	6	2	20	<1				
Total hardness as CaCO ₃	mg/L	11	12	11	14	16	16	40	36	67	62				
Conductivity at 25°C	µS/cm ⁽⁵⁾	54.2	43.7	44.0	46.2	42.9	48.1	100	113	201	201				
Nutrients															
Free and saline ammonia as N	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	4.4	<0.1	4.1	38.3 ^{(a)(b)}	2.47 ^{(a)(b)}	1.91 ^{(a)(b)}	
Nitrate (NO ₃)	mg/L	0.3	0.2	5.1	1.4	1.9	<0.1	0.3	0.2	3.3	0.2			13	50
Nitrite (NO ₂)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1			0.2	0.2
Total Kjeldahl nitrogen as N	mg/L	-	-	-	0.3	-	-	-	5	-	4.1				
Dissolved organic carbon (DOC)	mg/L	-	-	-	<1	-	-	-	3	-	8				
Total phosphorus	mg/L	<0.04	<0.04	<0.04	-	-	-	<0.04	<0.04	-	-				
Total phosphate (PO ₄)	mg/L	0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1				
Major Ions															
Bicarbonate (HCO ₃)	mg/L	12	17	15	21	21	22	49	49	73	76				
Calcium (Ca)	mg/L	2.5	2.6	2.2	3	3.6	3.7	12.9	10.3	17.9	16.6				
Chloride (Cl)	mg/L	8.5	7	6.1	5	4	5	6.5	11	20	21	860	230		
Fluoride (F)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1				1.5
Magnesium (Mg)	mg/L	1.2	1.3	1.3	1.6	1.6	1.6	2	2.4	5.4	4.9				
Potassium (K)	mg/L	0.1	<0.1	0.3	1	1.3	1.3	<0.1	2.3	2.7	2.6				
Sodium (Na)	mg/L	1.5	1.5	2	4	2.8	2.8	4.4	5.1	12.5	13.6				
Sulphate (SO ₄)	mg/L	5	1.9	1.6	<0.1	<0.1	<0.1	2.4	2.2	<0.1	6.2				
Total Metals															
Aluminum (Al)	mg/L	0.04	0.03	0.61	0.02	0.02	0.03	0.06	0.02	0.2	0.25	0.75	0.087	0.005 to 0.1 ^(d)	
Antimony (Sb)	mg/L	<0.0006	<0.0006	<0.0001	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006				0.02
Arsenic (As)	mg/L	0.003	0.0057	<0.0006	<0.0002	<0.0002	<0.0002	0.0076	0.0061	0.0297	0.0287	0.34	0.15	0.005	0.01
Barium (Ba)	mg/L	0.02	0.01	0.03	0.02	0.01	0.02	0.01	0.006	0.02	0.03				0.7
Beryllium (Be)	mg/L	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002				
Bismuth, (Bi)	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005				
Boron (B)	mg/L	0.01	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	0.02	0.01	0.03				0.5
Cadmium (Cd)	mg/L	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.0002 ^{(b)(c)}	0.00004 ^{(b)(c)}	0.000017	0.003
Chromium, total (Cr)	mg/L	<0.003	<0.003	0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	0.016	0.001	0.001	0.05
Chromium (Cr ⁺⁶)	mg/L	-	-	-	-	-	-	-	-	-	-				
Gallium (Ga)	mg/L	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.002	<0.002				
Germanium (Ge)	mg/L	<0.012	<0.012	<0.012	<0.01	<0.01	<0.01	<0.012	<0.012	<0.01	<0.01				
Gold (Au)	mg/L	<0.004	<0.004	<0.004	-	-	-	<0.004	<0.004	-	-				
Cobalt (Co)	mg/L	<0.001	<0.001	0.006	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001				
Copper (Cu)	mg/L	0.009	<0.002	0.004	<0.002	<0.002	<0.002	0.003	0.002	<0.002	0.007	0.0013 ^{(b)(c)}	0.0011 ^{(b)(c)}	0.002 ^{(b)(c)}	2
Indium (In)	mg/L	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	0.006	<0.004				

Table 9.1-14 Water Quality Results from Process Plant Area (Dry Season 2004) (continued)

Parameters	Units	Identification Sample – Sampling Date										Guidelines			
												Aquatic Life ⁽¹⁾⁽²⁾		Drinking Water	
		QESF 223	QESF 224	QESF 225	QESF 226	QESF 227	QESF 228	QESF 230	QESF 231	QESF 232	QESF 233	EPA		CCME	WHO ⁽³⁾
		07/11/2004	16/11/2004	14/11/2004	28/11/2004	28/11/2004	28/11/2004	17/11/2004	18/11/2004	27/11/2004	29/11/2004	Acute	Chronic	Chronic	
Iron (Fe)	mg/L	1.6	4.1	7.7	0.33	0.36	0.31	2.4	1.2	1.5	1.6		1	0.3	
Lead (Pb)	mg/L	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.003 ^{(b)(c)}	0.0001 ^{(b)(c)}	0.0001 to 0.0007	0.01
Manganese (Mn)	mg/L	0.36	0.04	0.42	0.02	0.02	0.02	0.03	0.03	0.08	0.08				0.4
Mercury (Hg)	mg/L	<0.0003	<0.0003	0.0004	<0.0003	0.0006	0.0003	<0.0003	<0.0003	<0.0003	<0.0003	0.0016	0.0001	0.0001	0.001
Molybdenum (Mo)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001			0.073	0.07
Nickel (Ni)	mg/L	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	0.055 ^{(b)(c)}	0.006 ^{(b)(c)}	0.025 to 0.15	0.02
Selenium (Se)	mg/L	<0.0001	<0.0001	<0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001			0.001	0.01
Silicon (Si)	mg/L	4.4	3	<0.007	9.6	9.6	9.6	2.6	3.6	5.9	4.9				
Silver (Ag)	mg/L	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	0.0001 ^{(b)(c)}		0.0001	
Strontium (Sr)	mg/L	0.02	0.02	0.02	0.02	0.02	0.02	0.11	0.1	0.18	0.13				
Thallium (Tl)	mg/L	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009			0.0008	
Tellurium (Te)	mg/L	<0.012	<0.012	<0.012	<0.01	<0.01	<0.01	<0.012	<0.012	<0.01	<0.01				
Thorium (Th)	mg/L	-	-	-	<0.002	<0.002	<0.002	-	-	<0.002	<0.002				
Tin (Sn)	mg/L	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02				
Titanium (Ti)	mg/L	<0.001	<0.001	0.02	0.004	0.003	0.002	0.001	<0.001	0.009	0.008				
Uranium (U)	mg/L	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004				0.015
Vanadium (V)	mg/L	<0.002	<0.002	0.01	0.003	0.004	0.005	<0.002	<0.002	0.008	0.004				
Zinc (Zn)	mg/L	0.02	<0.005	<0.005	0.03	0.02	0.08	0.1	<0.005	0.05	0.08	0.014 ^{(b)(c)}	0.014 ^{(b)(c)}	0.03	
Zirconium (Zr)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001				
Biological Parameters															
Total coliforms	CFU/100 ml	20	28	43	28	93	28	4,600	11,000	11,00	11,00				
Organics															
Oil and grease	mg/L	5.2	6.4	<0.2	1	<0.2	0.8	4.8	6	6.2	13.4				
Biochemical oxygen demand (BOD)	mg/L	-	-	-	1.1	-	-	-	1.5	-	2.5				
Chemical oxygen demand (COD)	mg/L	-	-	-	50	-	-	-	50	-	57				
Madagascar classification ⁽⁶⁾		A	B	C	C	B	B	HC	HC	B	C				

Notes: Guidelines are from United States Environment Protection Agency (U.S. EPA) 2004. National Recommended Water Quality Criteria; CCME (Canadian Council of Ministers of the Environment) Guidelines (2003) and WHO (World Health Organization) 2004.

⁽¹⁾ Values above (or below, for pH and dissolved oxygen) chronic guidelines are shown in bold.

⁽²⁾ Values above acute guidelines are shown in italics.

⁽³⁾ Values above WHO guidelines are highlighted.

⁽⁴⁾ pH Value at 21 °C for QESF 225, pH Value at 23 °C for QESF 230, 231, 233 and pH Value at 24 °C for QESF 226 to QESF 228 and QESF 232.

⁽⁵⁾ Results were compared to classifications values in Table 9.1-6, with the worse class for any given parameter used to assign an overall classification at each station.

⁽⁶⁾ Laboratory conductivity values were reported in mS/m but are reported in µS/cm for comparison to dry season.

^(a) The 1-hour concentration of total ammonia nitrogen (in mg N/L) does not exceed, more than once in every three years on average, the CMC (acute criterion) calculated using the following equation:
CMC= (0.411/1+10 7.204-pH) + (58.4/+10 pH-7.204)
The 30-day average concentration of total ammonia nitrogen (in mg N/L) does not exceed, more than once in every three years on average, the CCC (chronic criterion) calculated using the following equations.
CCC = ((0.577/1+10 7.688-pH) + (2.487/+10 pH-7.688) * MIN (2.85, 1.45 * 10 0.028 * (25-T))
U.S. EPA (1999)

^(b) When the criteria is a function of pH, hardness or temperature, the number presented in this table is based on pH of 6.9, total hardness of 10 mg/L and a temperature of 28.4. For comparison to guidelines, a criteria was calculated for each result based on the observed pH, hardness and/or temperature at the station.

^(c) The freshwater criterion for this metal is expressed as a function of hardness (mg/L) in the water column. Criteria values for each result were calculated from the following:
CMC (dissolved) = exp(mA [ln(hardness)]+ bA) (CF), or CCC(dissolved) = exp(mC [ln (hardness)]+ bC) (CF) and the parameters specified in Appendix B- Parameters for Calculating Freshwater Dissolved Metals Criteria That Are Hardness-Dependent

^(d) Aluminum guideline is 0.005 mg/L when pH<6.5 or calcium <4 mg/L and 0.1 mg/L when pH=>6.5 and calcium => 4 mg/L.

- Not available.

CCC = Criteria Continuous Concentration (chronic value).

CMC = Criteria Maximum Concentration (acute value).

The majority of results were below guidelines; however, there were a number of parameters results that did not meet aquatic life and/or drinking water guidelines at one or more stations (Table 9.1-15). As discussed previously (Section 2.3.1.2), caution must be exercised when interpreting values that do not meet guidelines that are not locally derived.

Based on the Madagascar classification system, most water bodies in the process plant area were Class B or Class C (Tables 9.1-13 and 9.1-14), which indicates most of the water is likely not suitable for swimming. The B and C classification were primarily due to results for pH, dissolved oxygen, water temperature, and COD (Tables 9.1-14). In the wet season data, two stations were classified as excessively contaminated (Class HC) due to dissolved oxygen (QESF-223) and TSS results (QESF-225). In the dry season, two stations were classified as Class HC due to dissolved oxygen results (QESF-230 and QESF-231).

There were few results that were above drinking water supply guidelines. Three parameters were above drinking water guidelines within the process plant area, including arsenic (QESF-232 and 233 in the Pangalanes Canal), manganese (QESF-223 and QESF-225) and lead (QESF-226).

Values of dissolved oxygen and pH were occasionally below aquatic life guidelines. Similar to the mine area, values of pH appear to be below aquatic life guidelines more frequently at stations within wetlands channels. Iron and aluminum appeared to have the greatest number of results above aquatic life guidelines. Results from the Invondro River were above aquatic life guidelines for cadmium, iron, lead, mercury and zinc (only dry season results available) while results from the Pangalanes Canal were above aquatic life guidelines for ammonia, aluminum, arsenic, iron and zinc.

For some parameters, results below detection limits could not be compared to guidelines because the method detection limits were greater than the guidelines. For wet season sampling, the detection limits for all metals were above the lowest guidelines, with the exception of iron, manganese and zinc. In the dry season, detection limits for cadmium, chromium, lead, mercury, silver and thallium were below the lowest guidelines.

Table 9.1-15 Madagascar Classifications and Number of Stations in the Process Plant Area with Results Above Guidelines

Parameter	Aquatic Life ^(a)		Drinking Water ^(b)		Madagascar Classifications ^(c)	
	Wet Season (out of 11)	Dry Season (out of 10 ^d)	Wet Season (out of 11)	Dry Season (out of 10 ^d)	Wet Season (out of 11)	Dry Season (out of 10 ^d)
Field pH ^(e)	4	4	n/a	n/a	1 B 1 C	3 B
Dissolved oxygen ^(e)	6	4	n/a	n/a	4 B 1 HC	2 B 2 HC
Field conductivity	n/a	n/a	n/a	n/a	1 B 1 C	all A
Water temperature	n/a	n/a	n/a	n/a	7 B 3 C	all B
TSS	n/a	n/a	n/a	n/a	1 HC	1 C
BOD ^(f)	n/a	n/a	n/a	n/a	-	all A
COD ^(f)	n/a	n/a	n/a	n/a	-	all C
Ammonia	0	2	n/a	n/a	n/a	n/a
Aluminum	5	7	n/a	n/a	n/a	n/a
Arsenic	0	5	0	2	n/a	n/a
Cadmium	0	1	0	0	n/a	n/a
Chromium	1	1	n/a	n/a	n/a	n/a
Copper	0	5	0	0	n/a	n/a
Iron	10	10	n/a	n/a	n/a	n/a
Lead	0	1	0	1	n/a	n/a
Manganese	n/a	n/a	1	1	n/a	n/a
Mercury	0	3	0	0	n/a	n/a
Zinc	0	6	n/a	n/a	n/a	n/a

n/a = Not applicable (i.e., no guidelines).

- = Parameter not analyzed.

^(a) Aquatic life guidelines are the most stringent of EPA (2004) or CCME (2003) guidelines.

^(b) Drinking water guidelines are from WHO (2004).

^(c) These classifications are based on the ranges and classifications specified in Table 9.1-5. All results were classified as Type A unless otherwise noted.

^(d) Field measurements were not taken at one station (QESF-223), therefore field measurements (pH and dissolved oxygen) are only out of 9 stations.

^(e) The guideline is a lower limit (dissolved oxygen) or a range (pH) and results were below guidelines.

^(f) Only three stations had results for BOD and COD in the dry season in the process plant area.

3.3.1.2 Seasonal Patterns

Only three stations (QESF 223 to 225) were monitored within the process plant area for both wet and dry seasons. A seasonal assessment of field parameters could not be completed because these parameters were not measured at

QESF-223 in the dry season. Several parameters that had consistently higher levels in the wet season compared to the dry season including:

- total hardness;
- magnesium;
- potassium;
- aluminum;
- boron; and
- tin.

No parameters were consistently higher in the dry season compared to the wet season. Because the results from only three stations were assessed, the individual results at the three stations are presented in Table 9.1-16.

Table 9.1-16 Summary Statistics of Parameters with Apparent Season Patterns in the Process Plant Area

Parameter	Units	Wet Season			Dry Season		
		QESF-223	QESF-224	QESF-225	QESF-223	QESF-224	QESF-225
Parameters Greater in Wet Season							
Potassium	mg/L	4.0	0.5	0.6	0.1	<0.1	0.3
Aluminum	mg/L	0.06	0.06	0.77	0.03	0.04	0.61
Boron	mg/L	0.06	0.04	0.01	0.01	<0.006	<0.006
Tin	mg/L	5.08	1.89	2.06	<0.02	<0.02	<0.02

In general, parameters associated with TSS would be expected to be higher in the wet season due to runoff events and parameters associated with groundwater (i.e., many of the major ions) would be expected to be higher in the dry season, due to dilution effects. However, based on the 2004 results, this pattern was not consistently observed in the process plant area.

3.3.1.3 Spatial Patterns

The following potential spatial patterns were observed for stations within the process plant area for both seasons, unless otherwise specified:

- lower pH values observed in the wetlands stations (QESF-230 and 231, only sampled in dry season) compared to other stations;

- higher concentrations of TDS, sodium, potassium, chloride, bicarbonate, calcium and magnesium in the stations on the Pangalanes Canal and QESF-231 compared to other stations;
- higher concentrations of total hardness and total alkalinity at the stations on the Pangalanes Canal compared to other stations;
- higher sulphate concentrations in the wetlands stations (QESF-230 and 231, only sampled in dry season) compared to other stations;
- higher TSS, manganese, iron, total coliform (only in the wet season), tin (only in the wet season) and aluminum at the tributary of the Ivondro River station (QESF-225) compared to other stations;
- higher total coliforms, aluminum, manganese, iron and tin concentrations at stations QESF-223 and 224 in the wet season; and
- lower silicon concentration at the tributary of the Ivondro River station (QESF-225) in the dry season compared to other stations.

The elevated TSS, bacteria and metals concentrations observed at station QESF-225 (tributary to the Ivondro River) and QESF-223 (pond) were likely due to the dominance of very soft clay and silt material in the bed and along the banks, as documented in the field notes for these stations. The higher concentrations of many of the major ions and related parameters at the stations along the Pangalanes Canal may be related to its proximity and connection to ocean waters.

3.3.2 Sediment Quality

3.3.2.1 Sediment Quality Characterization and Comparison to Guidelines

The sediment quality results from the three stations sampled in the process plant area in 2004 are presented in Table 9.1-17. The sediment sample collected at station QESF-226, located on the Ivondro River, was predominantly made up of coarser material (sand =73% and gravel =5%). The sediment samples taken from the Pangalanes Canal (QESF-233) and at station QESF-230 were predominantly sand and silt. The results of carbon and nitrogen sediment parameters were generally higher at stations QESF-232 and 230 and available phosphorus was greatest at station QESF-230 (27 mg/kg), which may be due to its location in a wetlands channel.

Sediment quality results for arsenic from the Pangalanes Canal (QESF-233) and nickel from the Ivondro River (QESF-226) were above the Canadian PEL guideline and the NOAA TEL, respectively. All other sediment quality parameters were below CCME guidelines and NOAA thresholds.

Table 9.1-17 Sediment Quality Results from Process Plant Area (2004)

Parameters	Units	Identification Sample - Sampling Date			Sediment Quality Guidelines ⁽¹⁾	
		QESF 226	QESF 231	QESF 233	ISQG ⁽²⁾	PEL ⁽³⁾
		28/11/2004	18/11/2004	29/11/2004		
Nutrients						
Nitrogen (N)	%	0.02	0.17	0.21		
Total oxidisable carbon (C) (by calculation)	%	0.5	2.29	17.6		
Carbonate as CO ₃	%	<0.05	<0.05	1.06		
Total carbon (C)	%	0.5	2.29	17.8		
Available phosphorous (P)	mg/kg	3	27	1		
Total Metals						
Aluminum (Al)	mg/kg	5.99% ^(a)	324	8,012		
Antimony (Sb)	mg/kg	<2	<2	<2		
Arsenic (As)	mg/kg	<4	<4	64	5.9	17
Barium (Ba)	mg/kg	73	<0.2	6.6		
Beryllium (Be)	mg/kg	<0.4	<0.4	<0.4		
Boron (B)	mg/kg	<1.2	<1.2	<1.2		
Cadmium (Cd)	mg/kg	<0.2	<0.2	<0.2	0.6	3.5
Calcium (Ca)	mg/kg	261	505	917		
Cobalt (Co)	mg/kg	14.8	<0.2	3.3		
Copper (Cu)	mg/kg	12.6	2.9	3.6	35.7	197
Iron (Fe)	mg/kg	2.59% ^(a)	2,426	1.28% ^(a)		
Lead (Pb)	mg/kg	12.5	<2	10.3	35	91.3
Magnesium (Mg)	mg/kg	3,180	52	305		
Manganese (Mn)	mg/kg	212	5.9	48		
Mercury (Hg)	mg/kg	<2	<2	<2	0.17	0.486
Nickel (Ni)	mg/kg	18.5	<0.6	8.6	18	35.9
Potassium (K)	mg/kg	3,592	6.7	128		
Selenium (Se)	mg/kg	<6	<6	<6		
Sodium (Na)	mg/kg	63	<4	<4		
Thallium (Tl)	mg/kg	<2	<2	<2		
Thorium (Th)	mg/kg	3	3.2	1.2		
Tin (Sn)	mg/kg	<4	<4	<4		
Uranium (U)	mg/kg	<0.8	<0.8	<0.8		
Vanadium (V)	mg/kg	41	0.75	17.7		
Zinc (Zn)	mg/kg	83	<1	3.6	123	315
Grain Size						
Cobbles (100 - 20 mm)	%	0	0	0		
Gravels (20 - 2 mm)	%	5	0	3		
Coarse sand (2 – 0.2 mm)	%	55	0	27		
Fine sand (0.2 – 0.02 mm)	%	18	47	32		
Silt (0.02 mm - 2 μ)	%	12	41	28		
Clay (2 – 1 μ)	%	10	12	10		

⁽¹⁾ Sediment Quality Guidelines are from CCME (Canadian Council of Ministers of the Environment) Guidelines (2003), with the exception of nickel which is from the United States National Oceanographic and Atmospheric Association (NOAA) (1999).

⁽²⁾ Values above the Interim Sediment Quality Guideline (or Threshold Effect Level for nickel) are shown in bold.

⁽³⁾ Values above the Probable Effect Level (PEL) are shown in italics.

^(a) Result reported as % instead of mg/kg.

3.3.2.2 Spatial Patterns

Among the three stations sampled in the process plant area, the station along the Ivondro River (QESF-226) had the highest metals concentrations for almost all of the metal parameters that had results above detection limits (Table 9.1-16). This result was not expected based on the higher proportion of sands and gravels observed at QESF-226 because metals are typically associated with the fine fraction of the sediment.

3.3.3 Summary

3.3.3.1 Water Quality

Based on pH measurements, the water bodies in the process plant area ranged from acidic to almost neutral. Dissolved oxygen measurements were generally at or below saturation. Water temperatures were measured in a relatively high range for stations around the process plant area in both the wet and dry seasons (25.6 to 32.2°C).

The hardness of the water at most stations was characterized as very soft, but ranged from very soft to moderately soft. A few water bodies around the process plant area appeared to be potentially sensitive to acidification based on observed alkalinity values. Nutrient levels were generally low for nitrogen parameters, including nitrate, nitrite, TKN and ammonia, and generally below detection limits for total phosphate.

Observed concentrations for many metals were below detection limits. Aluminum, boron, iron and manganese were generally above detection limits in the wet season. Dry season results for aluminum, arsenic, barium, iron, manganese, silicon, strontium, titanium, vanadium and zinc were typically above detection limits for stations in the process plant area.

Three parameters were above drinking guidelines, including arsenic, lead and manganese in the process plant area. In terms of field parameters, pH and dissolved oxygen values were occasionally below aquatic biota guidelines. Results for ammonia and nine metals (aluminum, arsenic, chromium, copper, iron, lead, mercury, nickel and zinc) were above aquatic life guidelines.

Clear seasonal and spatial patterns in water quality were not observed in the process plant area, with the exception of the following parameters and locations. Results for total hardness, magnesium, potassium, aluminum, boron and tin appear to be greater in the wet season compared to the dry season. The observed

higher concentrations of many of the major ions and related parameters (i.e., total alkalinity, hardness and dissolved solids) in the Pangalanes Canal are likely related to the canal's connection to the ocean.

3.3.3.2 Sediment Quality

Observed ranges in nitrogen, carbon and phosphorus levels in sediment samples collected in the process plant area were relatively large, which may be due to the wide range in observed particle size distribution (predominately coarse material to predominantly fine material). Sediment quality results for arsenic and nickel were above the Canadian PEL guideline and the NOAA TEL, respectively. All other sediment quality parameters were below CCME guidelines and NOAA thresholds.

3.4 TAILINGS FACILITY

3.4.1 Water Quality

3.4.1.1 Water Quality Characterization and Comparison to Guidelines

Water quality data collected within the tailings facility area in 2004 during the wet and dry seasons are presented in Tables 9.1-18 and 9.1-19, respectively. The overall water quality class, based on the Madagascar classification system, for each station is also presented in Tables 9.1-18 and 9.1-19.

Based on field measurements from the tailings facility area, the water bodies ranged from moderately acidic (pH of 5.5) to almost neutral (pH of 7.1). Dissolved oxygen measurements were generally below saturation and ranged from 2.9 mg/L to 9.6 mg/L. Measurements of water temperatures ranged from 23°C at station QESF-213 to 32.2°C at station QESF-222.

The observed hardness of the water within the tailing facilities area was consistently very soft (9 to 16 mg/L hardness), with one exception at station QESF-206 (26 mg/L hardness). All results for alkalinity (6 to 18 mg/L) indicated that the water bodies within the tailing facilities area are potentially sensitive to acidification, with the exception of the alkalinity result at QESF-206 (24 mg/L). Observed ranges in TDS (12 to 248 mg/L) and TSS (<2 to 18 mg/L) within the tailings facility area were both considered to be low to moderate.

Table 9.1-18 Water Quality Results from Tailings Facility Area (Wet Season 2004)

Parameters	Units	Sample Station-Sample Collection Date																	Guidelines			
																			Aquatic Life ^{1,2}			Drinking Water
		QESF 200	QESF 201	QESF 202	QESF 203	QESF 204	QESF 206	QESF 207	QESF 209	QESF 209b (duplicate)	QESF 210	QESF 211	QESF 213	QESF 214	QESF 215	QESF 216	QESF 221	QESF 222	EPA		CCME	WHO ³
		8-Mar	8-Mar	9-Mar	10-Mar	9-Mar	10-Mar	10-Mar	11-Mar	11-Mar	11-Mar	11-Mar	13-Mar	13-Mar	13-Mar	14-Mar	15-Apr	15-Apr	Acute	Chronic	Chronic	
Field Parameters																						
pH	pH units	5.94	5.48	6.03	6.07	6.1	6.72	5.94	6.12	-	6.84	6.77	6.42	7.14	6.42	6.7	5.84	6.52		6.5 - 9	6.5 - 9	
Total dissolved solids	mg/L	26	44	22	21	21	45	20	23	-	22	22	25	21	25	27	24	28				
Conductivity	µS/cm	42	46	36	33	36	75	33	37	-	35	35	39	32	40	48	39	49				
Turbidity	NTU	6.2	13.5	5.7	4.68	4.43	10.59	5.2	4.7	-	4.6	3.2	8.36	4.08	9.82	-	3.73	6.8				
Temperature	°C	27.59	27.46	28.36	27.82	28.13	28.86	27.99	25.68	-	25.95	26.64	27.37	25.13	28	31.89	28.23	32.2				
Dissolved oxygen	mg/L	5.33	4.42	7.84	4.6	5.57	3.31	4.05	6.67	-	7.17	7.96	5.68	9.54	4.32	4.47	2.37	2.95	5	6	5.5 to 6	
Dissolved oxygen	%	68	55.8	75.1	58.3	71.2	43	51.7	81.8	-	88.2	99	72	116	55.1	61.4	30.4	40.4				
Redox potential	mV	165.6	208.7	140.3	113.9	99.5	29.9	135.6	92.7	-	53	81.6	72.9	77.6	37.8	72.2	104.3	95				
Conventional Parameters																						
pH value at 20 °C	pH units	6.4	5.8	6.5	6.4	6.3	7.2	3.6	6.6	6.6	7	7	6.7	6.9	6.9	5.5	6.2	6.4		6.5 - 9	6.5 - 9	
Total alkalinity as CaCO ₃	mg/L	8	12	8	6	6	24	9	11	11	10	10	11	9	9	11	6	7				
Total dissolved solids	mg/L	80	80	56	32	66	230	248	82	78	122	110	84	114	30	78	68	20				
Total suspended solids	mg/L	2	9.5	3	4.5	4.5	6.5	5	2.5	2.5	1.5	3.5	2.5	3	2	3	3.5	4				
Total hardness as CaCO ₃	mg/L	7.2	4.2	6.1	8.6	6.4	26	10.5	9.6	9.8	8.6	6.1	11	8.8	9.6	12.6	7.1	9.9				
Conductivity at 25°C	µS/cm	73.7	34.9	46.6	36	35.4	80.5	37.7	54.9	41.7	40.1	35.8	42.7	37.8	39.4	77	48	71.2				
Nutrients																						
Ammonia as N	mg/L	<0.1	<0.1	0.2	0.3	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	38.3 ^{a,b}	2.47 ^{a,b}	1.91 ^{a,b}	
Nitrate (NO ₃)	mg/L	<0.1	0.1	0.3	0.5	0.5	0.8	0.5	<0.1	0.3	0.2	0.2	<0.1	<0.1	<0.1	0.1	<0.1	0.3			13	50
Nitrite (NO ₂)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1			0.2	0.2
Total phosphate (PO ₄)	mg/L	0.2	0.1	0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1				
Major Ions																						
Bicarbonate (HCO ₃)	mg/L	10	15	10	7	7	29	11	13	13	12	12	13	11	11	13	7	9				
Carbonate (CO ₃)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-				
Calcium (Ca)	mg/L	1.4	0.7	1.3	2.3	1.4	7.8	2.9	1.7	1.6	1.3	0.8	2.1	1.4	1.2	1.9	1.2	2				
Chloride (Cl)	mg/L	7.8	5.7	7.8	7.3	6.7	6.2	7.8	5.7	6.2	5.7	6.2	5.7	5.2	5.2	5.2	6.7	7.8	860	230		
Fluoride (F)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1				1.5
Magnesium (Mg)	mg/L	0.9	0.6	0.7	0.7	0.7	1.5	0.8	1.3	1.4	1.3	1	0.4	1.3	1.6	1.9	1	1.2				
Potassium (K)	mg/L	0.2	0.6	0.1	<0.1	<0.1	0.3	<0.1	<0.1	0.7	<0.1	<0.1	0.4	<0.1	<0.1	0.7	1.8	0.7				
Sodium (Na)	mg/L	4.5	3.1	4.2	3.9	4.1	3.6	3.8	3.6	3.5	3.5	3.1	3.7	3.1	3.4	3.7	4	3.7				
Sulphate (SO ₄)	mg/L	1.8	1.6	1.6	1	1.4	3.5	3	1.9	0.3	1.6	1.6	2.7	2.4	1.9	2.2	4.5	0.5				
Total Metals																						
Aluminum (Al)	mg/L	0.07	0.11	0.07	0.03	<0.01	0.39	0.03	<0.01	<0.01	0.11	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.03	0.75	0.087	0.005 to 0.1 ^d	
Antimony (Sb)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1				0.02
Arsenic (As)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.34	0.15	0.005	0.01
Barium (Ba)	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05				0.7
Beryllium (Be)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01				
Boron (B)	mg/L	0.03	0.03	0.02	0.01	<0.01	0.01	0.01	0.01	0.01	0.06	0.01	0.01	<0.01	0.01	0.01	0.02	0.03				0.5
Cadmium (Cd)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0002 ^{b,c}	0.00004 ^{b,c}	0.000017	0.003
Chromium, total (Cr)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.016	0.001	0.001	0.05
Chromium (Cr ⁺⁶)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01				
Cobalt (Co)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01				
Copper (Cu)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0013 ^{b,c}	0.0011 ^{bc}	0.002 ^{b,c}	2
Iron (Fe)	mg/L	0.44	0.77	0.92	1.2	1.1	0.72	1.6	0.78	0.79	0.58	0.37	0.81	0.35	2.2	1.5	1.3	2.61		1	0.3	

Table 9.1-18 Water Quality Results from Tailings Facility Area (Wet Season 2004) (continued)

Parameters	Units	Sample Station-Sample Collection Date																	Guidelines			
																			Aquatic Life ^{1,2}			Drinking Water
		QESF 200	QESF 201	QESF 202	QESF 203	QESF 204	QESF 206	QESF 207	QESF 209	QESF 209b (duplicate)	QESF 210	QESF 211	QESF 213	QESF 214	QESF 215	QESF 216	QESF 221	QESF 222	EPA		CCME	WHO ³
		8-Mar	8-Mar	9-Mar	10-Mar	9-Mar	10-Mar	10-Mar	11-Mar	11-Mar	11-Mar	11-Mar	13-Mar	13-Mar	13-Mar	14-Mar	15-Apr	15-Apr	Acute	Chronic	Chronic	
Lead (Pb)	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.003 ^{b,c}	0.0001 ^{b,c}	0.0001 to 0.0007	0.01
Manganese (Mn)	mg/L	0.02	0.01	<0.01	0.02	0.03	0.03	0.04	0.05	0.06	0.06	0.01	0.11	0.02	0.12	0.08	0.27	0.42				0.4
Mercury (Hg)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.0016	0.0001	0.0001	0.001
Nickel (Ni)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.055 ^{b,c}	0.006 ^{b,c}	0.025 to 0.15	0.02
Selenium (Se)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01			0.001	0.01
Thorium (Th)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01				
Tin (Sn)	mg/L	0.16	0.28	0.34	0.43	0.42	0.26	0.59	0.28	0.28	0.21	0.14	0.3	0.13	0.79	0.52	0.47	0.96				
Uranium (U)	mg/L	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2				0.015
Vanadium (V)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01				
Zinc (Zn)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.014 ^{b,c}	0.014 ^{b,c}	0.03	
Biological Parameters																						
Total coliforms	CFU/100 ml	930	4,600	1,500	1,500	1,100	930	1,100	4,600	1,500	1,500	1,100	4,600	460	460	150	1,100	1,500				
Organics																						
Oil and grease	mg/L	9.8	18.2	16.4	19.6	<0.6	<0.2	20	<0.2	<0.2	0.2	7.1	<0.2	<0.2	5.8	7.2	8.8	11.2				
Madagascar classification ⁽⁵⁾		B	C	B	B	B	B	B	B	B	B	B	B	B	B	C	C	C				

Notes: Guidelines are from United States Environment Protection Agency (U.S. EPA) 2004. National Recommended Water Quality Criteria; CCME (Canadian Council of Ministers of the Environment) Guidelines (2003) and WHO (World Health Organization) 2004.

(1) Values above chronic guidelines are shown in bold.

(2) Values above acute guidelines are shown in italics.

(3) Values above WHO guidelines are highlighted.

(4) Results were compared to classifications values in Table 9.1-6, with the worse class for any given parameter used to assign an overall classification at each station.

(a) The 1-hour concentration of total ammonia nitrogen (in mg N/L) does not exceed, more than once in every three years on average, the CMC (acute criterion) calculated using the following equation:
CMC= (0.411/1+10 7.204-pH) + (58.4/+10 pH-7.204).
The 30-day average concentration of total ammonia nitrogen (in mg N/L) does not exceed, more than once in every three years on average, the CCC (chronic criterion) calculated using the following equations.
CCC = ((0.577/1+10 7.688-pH) + (2.487/+10 pH-7.688) * MIN (2.85, 1.45 * 10 0.028 * (25-T))).
U.S. EPA (1999).

(b) When the criteria is a function of pH, hardness or temperature, the number presented in this table is based on pH of 6.9, total hardness of 10 mg/L and a temperature of 28.4. For comparison to guidelines, a criteria was calculated for each result based on the observed pH, hardness and/or temperature at the station.

(c) The freshwater criterion for this metal is expressed as a function of hardness (mg/L) in the water column. Criteria values for each result were calculated from the following:
CMC (dissolved) = exp{mA [ln(hardness)]+ bA} (CF), or CCC(dissolved) = exp{mC [ln (hardness)]+ bC} (CF) and the parameters specified in Appendix B- Parameters for Calculating Freshwater Dissolved Metals Criteria That Are Hardness-Dependent

- Not available.

CCC = Criteria Continuous Concentration (chronic value).

CMC = Criteria Maximum Concentration (acute value).

Table 9.1-19 Water Quality Results from Tailings Facility Area (Dry Season 2004)

Parameters	Units	Identification Sample - Sampling Date															Guidelines			
		QESF 200	QESF 201	QESF 201b (duplicate)	QESF 202	QESF 203	QESF 204	QESF 207	QESF 209	QESF 210	QESF 211	QESF 213	QESF 214	QESF 215	QESF 216	QESF 400 (BLANK)	Aquatic Life ⁽¹⁾⁽²⁾		Drinking Water	
		14-Nov	14-Nov	14-Nov	15-Nov	15-Nov	17-Nov	15-Nov	19-Nov	19-Nov	19-Nov	16-Nov	17-Nov	16-Nov	20-Nov	18-Nov	EPA			CCME
																	Acute	Chronic		Chronic
Field Parameters																				
pH	pH units	5.63	5.88	-	5.54	5.47	5.85	5.6	6.5	6.6	6.88	6.06	7.07	6.02	6.06	-		6.5 - 9	6.5 - 9	
Total dissolved solids	mg/L	26	27	-	27	28	30	27	28	28	25	27	24	27	27	-				
Conductivity	µS/cm	41	44	-	44	45	48	43	43	43	39	41	36	43	42	-				
Turbidity	UTN	8.6	12	-	11	16	5.31	10	4.41	5.47	2.64	4.31	2.04	5.65	5.9	-				
Temperature	°C	25.92	27.55	-	28.31	28.29	27	27.98	25.12	24.8	26.23	24.4	23	25.92	24.78	-				
Dissolved oxygen	mg/L	6.27	4.65	-	4.28	4.86	4.87	4.33	8.05	7.37	7.71	7.17	7.97	6	6.07	-	5	6	5.5 to 6	
Dissolved oxygen	%	77.1	59	-	55.1	62.6	61	55.2	97.6	88.9	95.5	86	93	73.8	73.2	-				
Oxydo-reduction potential	mV	71.2	76.7	-	151.5	81.6	32.3	82.6	20.9	68.2	59.4	75	54.8	32.4	66.8	-				
Conventional Parameters																				
pH value @ 23°C ⁽⁴⁾	pH units	6.6	6.5	6.4	6	6.7	6.6	6.5	7.1	7	7.1	6.8	7.3	6.8	6.8	5.6		6.5 - 9	6.5 - 9	
Total alkalinity as CaCO ₃	mg/L	10	10	10	12	16	14	14	18	14	16	14	14	12	14	4				
Total dissolved solids	mg/L	12	30	30	68	60	52	64	58	58	60	54	58	30	56	22				
Total suspended solids	mg/L	7	9	6	18	10	18	16	< 2	8	< 2	< 2	10	10	10	4				
Total hardness as CaCO ₃	mg/L	9	9	9	9.6	13	11	12	16	13	14	13	14	14	14	2.1				
Conductivity @ 25°C	mS/m	4.2	4.37	4.35	4.59	6.15	3.94	4.23	4.38	3.67	5.08	4.33	4.12	4.11	4.46	0.218				
Nutrients																				
Free and saline ammonia as N	mg/L	< 0.1	0.6	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.6	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	38.3 ^{(a)(b)}	2.47 ^{(a)(b)}	1.91 ^{(a)(b)}	
Nitrate (NO ₃)	mg/L	6.6	4.7	3.2	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.6			13	50
Nitrite (NO ₂)	mg/L	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1			0.2	0.2
Total Kjeldahl nitrogen as N	mg/L	-	0.6	< 0.1	0.4	-	-	-	-	1.2	-	-	-	-	-	-				
Dissolved organic carbon (DOC)	mg/L	-	2	2	3	-	-	-	-	1	-	-	-	-	-	-				
Total phosphorus	mg/L	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	0.08	0.14	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04				
Total phosphate (PO ₄)	mg/L	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.2	0.4	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1				
Major Ions																				
Bicarbonate (HCO ₃)	mg/L	12	12	12	15	20	17	17	22	17	20	17	17	15	17	5				
Calcium (Ca)	mg/L	1.8	1.5	1.6	1.7	2.2	1.7	2	2.9	2.5	2.4	2.6	2.6	2	2.2	0.5				
Chloride (Cl)	mg/L	6.1	6.6	7.6	11	6	5.5	5.5	5.5	9	5.5	5.5	5	6	6	1	860	230		
Fluoride (F)	mg/L	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1				1.5
Magnesium (Mg)	mg/L	1	1.2	1.3	1.3	1.8	1.7	1.7	2.2	1.6	1.9	1.7	1.9	2.1	2	0.2				
Potassium (K)	mg/L	0.1	0.2	0.2	< 0.1	0.3	< 0.1	1.2	0.5	1.3	< 0.1	< 0.1	< 0.1	< 0.1	0.5	1.3				
Sodium (Na)	mg/L	2	2.1	2.1	1.4	4.4	4.7	2.1	1.3	3.4	1.3	1	4.7	4	1.3	< 0.1				
Sulphate (SO ₄)	mg/L	1.1	1.4	2.7	1.1	0.8	5.9	16	12.8	5.1	7.4	4.5	1.4	2.6	3.5	1.1				
Total Metals																				
Aluminum (Al)	mg/L	0.02	0.01	0.01	0.04	0.02	0.01	0.06	0.01	0.05	0.05	0.01	0.01	0.01	0.05	0.01	0.75	0.087	0.005 to 0.1 ^(d)	
Antimony (Sb)	mg/L	< 0.0006	< 0.0006	< 0.0006	< 0.0006	< 0.0006	< 0.0006	< 0.0006	< 0.0006	< 0.0006	< 0.0006	< 0.0006	< 0.0006	< 0.0006	< 0.0006	< 0.0006				0.02
Arsenic (As)	mg/L	< 0.0002	< 0.0002	< 0.0002	0.0002	0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0.0003	< 0.0002	< 0.0002	0.34	0.15	0.005	0.01
Barium (Ba)	mg/L	0.009	0.01	0.01	0.01	0.01	0.01	0.01	0.009	0.008	0.009	0.008	0.01	0.01	0.008	0.08				0.7
Beryllium (Be)	mg/L	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002				
Bismuth, Bi	mg/L	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005				
Boron (B)	mg/L	< 0.006	< 0.006	< 0.006	0.01	0.007	0.01	0.007	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006				0.5
Cadmium (Cd)	mg/L	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.0002 ^{(b)(c)}	0.00004 ^{(b)(c)}	0.000017	0.003
Chromium, total (Cr)	mg/L	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	0.016	0.001	0.001	0.05
Chromium (Cr ⁺⁶)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-				
Gallium (Ga)	mg/L	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002				
Germanium (Ge)	mg/L	< 0.012	< 0.012	< 0.012	< 0.012	< 0.012	< 0.012	< 0.012	< 0.012	< 0.012	< 0.012	< 0.012	< 0.012	< 0.012	< 0.012	< 0.012				
Gold (Au)	mg/L	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004				
Cobalt (Co)	mg/L	0.001	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001				
Copper (Cu)	mg/L	< 0.002	< 0.002	< 0.002	0.002	0.005	0.007	0.006	0.002	0.005	0.005	< 0.002	0.004	0.005	0.006	0.006	0.0013 ^{(b)(c)}	0.0011 ^{(b)(c)}	0.002 ^{(b)(c)}	2

Table 9.1-19 Water Quality Results from Tailings Facility Area (Dry Season 2004) (continued)

Parameters	Units	Identification Sample - Sampling Date															Guidelines			
		QESF 200	QESF 201	QESF 201b (duplicate)	QESF 202	QESF 203	QESF 204	QESF 207	QESF 209	QESF 210	QESF 211	QESF 213	QESF 214	QESF 215	QESF 216	QESF 400 (BLANK)	Aquatic Life ⁽¹⁾⁽²⁾		Drinking Water	
		14-Nov	14-Nov	14-Nov	15-Nov	15-Nov	17-Nov	15-Nov	19-Nov	19-Nov	19-Nov	16-Nov	17-Nov	16-Nov	20-Nov	18-Nov	EPA			CCME
																	Acute	Chronic		Chronic
Indium (In)	mg/L	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004				
Iron (Fe)	mg/L	1.2	1.9	2	4.1	3.4	5	2.6	0.82	0.65	0.6	1	0.37	2.2	1.4	0.002		1	0.3	
Lead (Pb)	mg/L	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.003 ^{(b)(c)}	0.0001 ^{(b)(c)}	0.0001 to 0.0007	0.01
Manganese (Mn)	mg/L	0.19	0.18	0.18	0.07	0.2	0.09	0.23	0.06	0.03	0.02	0.11	0.02	0.13	0.06	< 0.001				0.4
Mercury (Hg)	mg/L	< 0.0003	< 0.0003	< 0.0003	0.0003	< 0.0003	< 0.0003	0.0003	< 0.0003	< 0.0003	< 0.0003	< 0.0003	< 0.0003	< 0.0003	< 0.0003	< 0.0003	0.0016	0.0001	0.0001	0.001
Molybdenum (Mo)	mg/L	< 0.001	0.001	0.002	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001			0.073	0.07
Nickel (Ni)	mg/L	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	0.055 ^{(b)(c)}	0.006 ^{(b)(c)}	0.025 to 0.15	0.02
Selenium (Se)	mg/L	0.0002	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001			0.001	0.01
Silicon (Si)	mg/L	0.05	< 0.007	< 0.007	5.7	7	6	6.3	8.3	8.7	8	7.9	8	6.9	7.9	< 0.006				
Silver (Ag)	mg/L	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	0.0001 ^{(b)(c)}		0.0001	
Strontium (Sr)	mg/L	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.002				
Thallium (Tl)	mg/L	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009			0.0008	
Thorium (Th)																				
Tellurium (Te)	mg/L	< 0.012	< 0.012	< 0.012	< 0.012	< 0.012	< 0.012	< 0.012	< 0.012	< 0.012	< 0.012	< 0.012	< 0.012	< 0.012	< 0.012	< 0.012				
Tin (Sn)	mg/L	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02				
Titanium (Ti)	mg/L	0.001	0.001	0.001	0.001	< 0.001	< 0.001	0.002	< 0.001	< 0.001	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001				
Uranium (U)	mg/L	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004				0.015
Vanadium (V)	mg/L	0.002	0.002	0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002				
Zinc (Zn)	mg/L	< 0.005	< 0.005	0.02	0.03	0.26	< 0.005	0.05	0.02	0.04	< 0.005	0.01	0.02	0.02	0.07	0.01	0.014 ^{(b)(c)}	0.014 ^{(b)(c)}	0.03	
Zirconium (Zr)	mg/L	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001				
Biological Parameters																				
Total coliforms	CFU/100 ml	1,100	150	210	210	43	75	150	460	1100	4600	15	1100	150	< 3	< 3				
Organics																				
Oil and grease	mg/L	< 0.2	< 0.2	1.4	11.4	13.8	14.6	12.8	10.6	9	10	7	10	7.6	4.2	7.8				
Biochemical oxygen demand (BOD)	mg/L	-	0.8	0.8	0.7	-	-	-	-	1	-	-	-	-	-	-				
Chemical oxygen demand (COD)	mg/L	-	15	< 5	41	-	-	-	-	54	-	-	-	-	-	-				
Madagascar classification ⁽⁵⁾		B	B	B	B	C	B	B	B	C	B	A	A	B	A					

Notes: Guidelines are from United States Environment Protection Agency (U.S. EPA) 2004. National Recommended Water Quality Criteria; CCME (Canadian Council of Ministers of the Environment) Guidelines (2003) and WHO (World Health Organization) 2004.

(1) Values above chronic guidelines are shown in bold.

(2) Values above acute guidelines are shown in italics.

(3) Values above WHO guidelines are highlighted.

(4) pH Value at 21 °C for QESF 200 and pH Value at 22 °C for QESF 201 and 201b.

(5) Results were compared to classifications values in Table 9.1-6, with the worse class for any given parameter used to assign an overall classifications at each station.

(a) The 1-hour concentration of total ammonia nitrogen (in mg N/L) does not exceed, more than once in every three years on average, the CMC (acute criterion) calculated using the following equation:
CMC= (0.411/1+10^{7.204-pH₁}) + (58.4/+10^{pH-7.204}).

The 30-day average concentration of total ammonia nitrogen (in mg N/L) does not exceed, more than once in every three years on average, the CCC (chronic criterion) calculated using the following equations.
CCC = ((0.577/1+10^{7.688-pH}) + (2.487/+10^{pH-7.688}) * MIN (2.85, 1.45 * 10^{0.028 * (25-T)}).

U.S. EPA (1999).

(b) When the criteria is a function of pH, hardness or temperature, the number presented in this table is based on pH of 6.9, total hardness of 10 mg/L and a temperature of 28.4. For comparison to guidelines, a criteria was calculated for each result based on the observed pH, hardness and/or temperature at the station.

(c) The freshwater criterion for this metal is expressed as a function of hardness (mg/L) in the water column. Criteria values for each result were calculated from the following:
CMC (dissolved) = exp{mA [ln(hardness)]+ bA} (CF), or CCC(dissolved) = exp{mC [ln (hardness)]+ bC} (CF) and the parameters specified in Appendix B- Parameters for Calculating Freshwater Dissolved Metals Criteria That Are Hardness-Dependent.

(d) Aluminum guideline is 0.005 mg/L when pH<6.5 or calcium <4 mg/L and 0.1 mg/L when pH=>6.5 and calcium => 4 mg/L.

- Not available.

CCC = Criteria Continuous Concentration (chronic value).

CMC = Criteria Maximum Concentration (acute value).

Nutrient levels were generally low for nitrogen parameters, including nitrate, nitrite, TKN and ammonia, and generally below detection limits for total phosphate. All but two results (at QESF-207 and QESF-209) for total phosphorus were below detection limits during the dry season. Total phosphorus was not analyzed during the wet season. Nutrient status of water bodies are typically determined by their concentration of total phosphorus. Based on Table 6 of Attachment 9.1-3, the streams and rivers in the tailings facility area are not eutrophic, with the exception of the waterbodies sampled at QESF-207 and QESF-209. The detection limit used for total phosphorus (0.04 mg/L) is too high to allow any further determination of the nutrient status of other waterbodies within the tailings facility area.

Observed concentrations for many metals were below detection limits. Wet season results for aluminum, boron, iron, manganese and tin were above detection limits in the tailings facility area. Dry season results for aluminum, arsenic, barium, copper, iron, manganese, silicon, strontium, titanium, vanadium and zinc were typically above detection limits for stations in the tailings facility area. Most of the additional parameters above detection limits in the dry season are due to either lower detection limits (As, Ba and V) in the dry season or the parameter was not analyzed in the wet season (Si, Ti and St). Observed values in the dry season for arsenic, barium and vanadium were generally below the detection limits used in the wet season.

The majority of results were below guidelines; however several parameters did not meet aquatic life and drinking water guidelines, or both, at one or more stations (Table 9.1-19). However, as discussed previously (Section 2.3.1.2), caution must be exercised when interpreting values that do not meet guidelines because the guidelines used are not locally derived.

Based on the Madagascar classification system, most water bodies in the tailings facility area were Class B, with some water bodies classified as C (Tables 9.1-18 and 9.1-19). The B and C classifications were primarily due to results for pH, dissolved oxygen and water temperature (Tables 9.1-20). There were no water bodies that were considered to be excessively contaminated (Class HC) in the tailings facility area.

Table 9.1-20 Madagascar Classifications and Number of Stations in the Tailings Facility Area with Results Above Guidelines

Parameter	Aquatic Life ^(a)		Drinking Water ^(b)		Madagascar Classification ^(c)	
	Wet Season (out of 16)	Dry Season (out of 13)	Wet Season (out of 16)	Dry Season (out of 13)	Wet Season (out of 16)	Dry Season (out of 13)
Field pH ^(d)	10	9	n/a	n/a	3 B 1 C	5 B 1 C
Dissolved oxygen ^(d)	11	5	n/a	n/a	6 B 2 C	5 B
Field conductivity	n/a	n/a	n/a	n/a	all A	all A
Water temperature	n/a	n/a	n/a	n/a	14 B 2 C	9 B
TSS	n/a	n/a	n/a	n/a	all A	all A
BOD ^(e)	n/a	n/a	n/a	n/a	-	all A
COD ^(e)	n/a	n/a	n/a	n/a	-	1 B 1 C
Aluminum	7	9	n/a	n/a	n/a	n/a
Copper	0	10	0	0	n/a	n/a
Iron	15	13	n/a	n/a	n/a	n/a
Manganese	n/a	n/a	1	0	n/a	n/a
Zinc	0	6	n/a	n/a	n/a	n/a

n/a = Not applicable (i.e., no guideline).

- = Parameter not analyzed.

^(a) Aquatic life guidelines are the most stringent of EPA (2004) or CCME (2003) guidelines.

^(b) Drinking water guidelines are from WHO (2004).

^(c) These classifications are based on the ranges and classifications specified in Table 9.1-6. All results were classified as Type A unless otherwise noted.

^(d) The guideline is a lower limit (dissolved oxygen) or a range (pH) and results were below guidelines.

^(e) Only three stations had BOD and COD results in the process tailings facility area for the dry season.

The only parameter above drinking water supply guidelines in the tailings facilities area was manganese at station QESF-222.

The pH results from about two-thirds of the stations within the tailings facility area were below the guideline range for aquatic life. Dissolved oxygen levels did not meet aquatic life guidelines at 11 stations in the wet season and five stations in the dry season. Aluminum, copper, iron and zinc had the highest number of samples above aquatic life guidelines for metals within the tailings facility area.

Results below detection limits could not be compared to guidelines for some parameters because the method detection limits were greater than the guidelines. For wet season sampling, the detection limits for all metals were above the lowest guidelines, with the exception of iron, manganese and zinc. Detection

limits for cadmium, chromium, lead, mercury, silver and thallium were below the lowest guidelines during the dry season.

3.4.1.2 Seasonal Patterns

Consistent differences in concentrations between wet and dry seasons in 2004 were observed for only a few parameters based on a comparison of all available data at the 13 stations within the tailings facility area. Wet and dry season data were not comparable for most metal parameters, with the exception of aluminum, boron, iron, manganese, tin and zinc due to differences in detection limits. Parameters that appeared to have higher concentrations in the wet season compared to the dry season included:

- boron (11 of 13); and
- tin (13 of 13).

Other parameters appeared be higher in the dry season compared to the wet season, including:

- total alkalinity (12 of 13);
- total hardness (13 of 13);
- bicarbonate (12 of 13);
- magnesium (13 of 13); and
- zinc (11 out of 13).

In general, parameters associated with TSS such as metals would be expected to be higher in the wet season due to runoff events and parameters associated with groundwater (i.e., many of the major ions) would be expected to be higher in the dry season, due to dilution effects. The seasonal patterns observed for the above parameters, with the exception of conductivity and zinc, were consistent with these typical seasonal patterns.

Seasonal differences were also observed based on the groupings of stations in Table 9.1-21. Due to the lack of data available at these stations (n = 5 to 8), additional data would be needed to confirm seasonal differences. Data from the irrigation channel stations were not compared for seasonal differences because these had only two data points each. A seasonal assessment could not be completed for pond stations because the pond stations were only sampled in the wet season.

Table 9.1-21 Possible Season Patterns by Station Groupings in the Tailings Facility Area

Parameter	Higher in the Wet Season	Higher in the Dry Season
field pH	wetlands	
field conductivity		wetlands
field total dissolved solids		streams
water temperature	streams wetlands	
laboratory total dissolved solids	streams	
total suspended solids		wetlands
calcium		streams
iron		streams
oil and grease		streams

3.4.1.3 Spatial Patterns

The following potential spatial patterns were observed for stations within the tailing facilities area for both seasons, unless otherwise specified:

- lower pH values at wetlands stations compared to other stations in the dry season;
- higher manganese concentrations in tributary 2 and 3 of the Ambolona River in the dry season; and
- higher iron concentrations at wetlands stations compared to other stations.

The lower pH and higher iron concentrations observed in the wetlands stations may be related if the lower pH has caused dissolution of sediment iron into the water column. Clear spatial trends for other parameters and stations within the tailings facility area were not observed.

3.4.2 Sediment Quality

3.4.2.1 Sediment Quality Characterization and Comparison to Guidelines

The sediment quality results from the three stations sampled in the tailings facility area in 2004 are presented in Table 9.1-22. The sediment sample collected at station QESF-202, which is located in a wetlands channel, was predominantly made up of coarser material (sand =83% and gravel =1%). The sediment sample taken from station QESF-201, which is also in a wetlands channel, was mostly fine material (silt=48% and clay=26%). The sediment sampled at station QESF-210 (located in a watercourse) was predominantly sand (51%) and silt (33%). The results of carbon and nitrogen sediment parameters were generally higher at station QESF-201 and available phosphorus was greatest at station QESF-202 (12 mg/kg).

Table 9.1-22 Sediment Quality Results from Tailings Facility Area (2004)

Parameters	Units	Identification Sample - Sampling Date				Sediment Quality Guidelines ⁽¹⁾	
		QESF 201	QESF 201 B	QESF 202	QESF 210	ISQG ⁽²⁾	PEL ⁽³⁾
		11/14/2004	11/14/2004	11/15/2004	11/19/2004		
Nutrients							
Nitrogen (N)	%	0.1	0.25	0.14	0.07		
Total oxidisable carbon	%	5.83	6.14	1.32	2.87		
Carbonate as CO ₃	%	0.06	0.17	0.08	0.27		
Total carbon (C) (by calculation)	%	5.84	6.17	1.34	2.92		
Available phosphorous (P)	mg/kg	2	2	12	1		
Total Metals							
Aluminum (Al)	%	6.59%	5.30%	2.77%	6.15%		
Antimony (Sb)	mg/kg	<2	<2	<2	<2		
Arsenic (As)	mg/kg	<4	<4	<4	<4	5.9	17
Barium (Ba)	mg/kg	11	7.4	< 0.2	< 0.2		
Beryllium (Be)	mg/kg	<0.4	<0.4	<0.4	<0.4		
Boron (B)	mg/kg	<1.2	<1.2	<1.2	<1.2		
Cadmium (Cd)	mg/kg	<0.2	<0.2	<0.2	<0.2	0.6	3.5
Cobalt (Co)	mg/kg	9.6	8.9	4.3	9.9		
Copper (Cu)	mg/kg	26	17.3	7.7	52	35.7	197
Iron (Fe)	%	1.51%	1.40%	1.20%	7.07%		
Lead (Pb)	mg/kg	<2	<2	<2	<2	35	91.3
Manganese (Mn)	mg/kg	125	104	35	239		
Mercury (Hg)	mg/kg	<2	<2	<2	<2	0.17	0.486
Nickel (Ni)	mg/kg	56	46	15	37	18	35.9
Selenium (Se)	mg/kg	<6	<6	<6	<6		
Thallium (Tl)	mg/kg	<2	<2	<2	<2		
Thorium (Th)	mg/kg	16.8	0.79	0.86	< 0.4		

Table 9.1-22 Sediment Quality Results from Tailings Facility Area (2004) (continued)

Parameters	Units	Identification Sample - Sampling Date				Sediment Quality Guidelines ⁽¹⁾	
		QESF 201	QESF 201 B	QESF 202	QESF 210	ISQG ⁽²⁾	PEL ⁽³⁾
		11/14/2004	11/14/2004	11/15/2004	11/19/2004		
Tin (Sn)	mg/kg	<4	<4	<4	<4		
Uranium (U)	mg/kg	<0.8	<0.8	<0.8	<0.8		
Vanadium (V)	mg/kg	103	117	52	316		
Zinc (Zn)	mg/kg	<1	<1	<1	<1	123	315
Grain Size							
Cobbles (100 - 20 mm)	%	0	0	0	7		
Gravels (20 - 2 mm)	%	0	0	1	5		
Coarse sand (2 – 0.2 mm)	%	4	27	69	8		
Fine sand (0.2 – 0.02 mm)	%	22	24	14	10		
Silt (0.02 mm - 2 µ)	%	48	33	10	32		
Clay (2 - 1 µ)	%	26	16	6	38		

Notes:

- (1) Sediment Quality Guidelines are from CCME (Canadian Council of Ministers of the Environment) Guidelines (2003), with the exception of nickel which is from the United States National Oceanographic and Atmospheric Association (NOAA) (1999).
- (2) Values above the Interim Sediment Quality Guideline (or Threshold Effect Level for nickel) are shown in bold.
- (3) Values above the Probable Effect Level (PEL) are shown in italics.

Sediment quality results for copper from station QESF-210 and nickel from stations QESF-201 and 210 were above the Canadian ISQG and the NOAA PEL threshold, respectively. All other sediment quality parameters were below CCME guidelines and NOAA thresholds from samples collected within the tailings facility area.

3.4.2.2 Spatial Patterns

Among the three stations sampled in the tailings facilities area, station QESF-202 had the lowest metals concentrations for almost all of the metal parameters that had results above detection limits. However, this result was consistent with the higher proportion of sands and gravels observed at station QESF-202 because metals are typically associated with the fine fraction of the sediment. Therefore, no spatial pattern in sediment quality was observed in the tailings facility area.

3.4.3 Summary

3.4.3.1 Water Quality

Based on pH measurements, the water bodies in the tailings facility area ranged from moderately acidic to almost neutral. Dissolved oxygen measurements were generally below saturation. Measurements of water temperatures ranged from 23 to 32.2°C. The observed hardness of the water within the tailing facilities area was generally very soft. The majority of results for alkalinity indicated that the water bodies within the tailing facilities area are potentially sensitive to acidification. Nutrient levels were generally low for nitrogen parameters, including nitrate, nitrite, TKN and ammonia, and generally below detection limits for total phosphate.

Observed concentrations for many metals were below detection limits. Wet season results for aluminum, boron, iron, manganese and tin were above detection limits in the tailings facility area. Dry season results for aluminum, arsenic, barium, copper, iron, manganese, silicon, strontium, titanium, vanadium and zinc were typically above detection limits for stations in the tailings facility area.

Manganese was the only parameter above drinking water guidelines in the tailings facility area. In terms of field parameters, pH and dissolved oxygen values were occasionally below aquatic life guidelines. Results for four metals (aluminum, copper, iron and zinc) were above aquatic life guidelines.

Clear seasonal and spatial patterns in water quality were not observed in the tailings facility area, with the exception of the following parameters and locations. Levels of boron and tin appear to be greater in the wet season compared to the dry season. Conversely, levels of total alkalinity, total hardness, bicarbonate, magnesium and zinc appear to be higher in the dry season. Lower pH and higher iron concentrations were observed in the wetlands stations, which may be related if the lower pH has caused dissolution of sediment iron into the water column.

3.4.3.2 Sediment Quality

Observed ranges in nitrogen, carbon and phosphorus levels in sediment samples collected in the tailings facility area were relatively large, which may be due to the wide range in observed particles size distribution (predominately coarse material to predominantly fine material). Sediment quality results for copper and nickel were above the Canadian ISQG and the NOAA PEL threshold, respectively. All other sediment quality parameters were below CCME guidelines and NOAA thresholds from samples collected within the tailings facility area.

3.5 QUALITY ASSURANCE/QUALITY CONTROL (QA/QC) RESULTS

The majority of the water and sediment quality data received from the laboratory was determined to be acceptable through the QA/QC procedures outlined in the methods section. Results for samples from four stations (QESF 202, 203, 207 and 233) and two parameters (chloride and sulphate) did not meet QA/QC criteria. However, because these data were consistent with the observed results from the other sites, they were instead qualified (i.e., potential QA/QC issues noted), and were not removed from the data set for the purpose of interpretation.

In addition, two results for field pH (QESF-220 and QESF-223) and one result for sulphate (QESF-223) were also qualified based on observed laboratory pH values. The field pH values reported for these two stations of 7.3 and 3.73 varied substantially from the laboratory pH values of 10.5 and 6.3, respectively. The values reported for sulphate at QESF-223 were unusually low (<0.01 mg/L) compared to all other reported values (minimum of 1.4 mg/L) and compared to the low pH values reported for this sample.

A comparison of the requested detection limits and detection limits (DLs) provided by the laboratory for individual samples indicated that the DLs met the requested DLs for most results. When laboratory DLs differed from requested

DLs or reported values were below DLs, the cause was found to be a transcription error, which was corrected by the laboratory. The wet season metals data had substantially higher detection limits compared to dry season data because specific DLs were requested for dry season analyses.

Hold times for some samples were substantially exceeded in the dry season for samples from stations QESF 202, 203, 207 (eight days each) and QESF 233 (15 days). The results from these stations were qualified but not removed from the data set.

Most parameters were below detection limits in the field blank results (Table 9.1-23). Results that were above detection limits were less than 10 times the detection limit in the field blank samples, with the exception of calcium, chloride, bicarbonate, potassium, nitrate, sulphate and chemical oxygen demand. Reported values of chloride and sulphate are qualified because these parameters were greater than 10 times the detection in all blank samples and the blank results were close to the environmental sample results.

The units reported for the results were consistent with requested units with the exception of sediment samples for metals which occasionally were presented as percentage instead of mg/kg. Percentages were converted to mg/kg by multiplying by a factor of 10^4 when comparing to sediment quality guidelines.

Based on a comparison of hard copy laboratory results and excel spreadsheets, a few transcription errors into the data spreadsheets were found and corrected. In one case, the percent saturation results for dissolved oxygen at QESF-205 (wet season) data did not match the reported mg/L of dissolved oxygen. These data are presented for completeness but removed from data analysis. In a second case, total hardness was reported as 163 mg/L at QESF-227 (on the Ivondro River), which is located between stations QESF-226 and QESF-228 on the Ivondro River. Values of total hardness at these two stations were 14 and 16 mg/L. The high value at QESF-227 was found to be due to a decimal point error and the correct value of 16 mg/L was reported and used in the analysis.

Table 9.1-23 Field Blank Results from Wet and Dry Season (2004)

Parameters	Units	Sample ID and Date			
		QESF 150	QESF 160	QESF 300	QESF 400
		5-Mar-04	1-Apr-04	10-Nov-04	18-Nov-04
Conventional Parameters					
pH value at 25°C	pH units	6.2	5.7	5.6	5.6
Total alkalinity as CaCO ₃	mg/L	12	5	4	4
Total dissolved solids	mg/L	164	22	6	22
Total suspended solids	mg/L	0.5	0.5	< 1	4
Total hardness as CaCO ₃	mg/L	13.2	1.3	< 0.6	2.1
Conductivity at 25°C	µS/cm	3	2.88	0.22	0.218
Nutrients					
Free and saline ammonia as N	mg/L	0.1	< 0.1	< 0.1	< 0.1
Nitrate (NO ₃)	mg/L	< 0.1	0.1	6.3	0.6
Nitrite (NO ₂)	mg/L	< 0.1	< 0.1	< 0.1	< 0.1
Total Kjeldahl nitrogen as N	mg/L	-	-	< 0.1	-
Dissolved organic carbon (DOC)	mg/L	-	-	< 1	-
Total phosphate (PO ₄)	mg/L	< 0.1	0.3	< 0.1	< 0.1
Major Ions					
Bicarbonate (HCO ₃)	mg/L	15	6	5	5
Calcium (Ca)	mg/L	5.3	0.2	< 0.1	0.5
Chloride (Cl)	mg/L	1.6	1.6	1.5	1
Fluoride (F)	mg/L	< 0.1	< 0.1	< 0.1	< 0.1
Magnesium (Mg)	mg/L	< 0.1	0.2	< 0.1	0.2
Potassium (K)	mg/L	0.2	0.3	0.1	1.3
Sodium (Na)	mg/L	< 0.1	< 0.1	0.2	< 0.1
Sulphate (SO ₄)	mg/L	1.1	1.1	1.6	1.1
Total Metals					
Aluminum (Al)	mg/L	< 0.01	0.02	< 0.009	0.01
Antimony (Sb)	mg/L	< 0.1	< 0.1	< 0.0006	< 0.0006
Arsenic (As)	mg/L	< 0.01	< 0.01	< 0.0002	< 0.0002
Barium (Ba)	mg/L	< 0.05	< 0.05	0.001	0.08
Beryllium (Be)	mg/L	< 0.01	< 0.01	< 0.002	< 0.002
Bismuth (Bi)	mg/L	-	-	< 0.005	< 0.005
Boron (B)	mg/L	< 0.01	0.02	< 0.006	< 0.006
Cadmium (Cd)	mg/L	< 0.01	< 0.01	< 0.001	< 0.001
Chromium (Cr)	mg/L	< 0.01	< 0.01	< 0.003	< 0.003
Gallium (Ga)	mg/L	-	-	< 0.002	< 0.002
Germanium (Ge)	mg/L	-	-	< 0.012	< 0.012
Gold (Au)	mg/L	-	-	< 0.004	< 0.004

Table 9.1-23 Field Blank Results from Wet and Dry Season (2004) (continued)

Parameters	Units	Sample ID and Date			
		QESF 150	QESF 160	QESF 300	QESF 400
		5-Mar-04	1-Apr-04	10-Nov-04	18-Nov-04
Chromium (Cr ⁺⁶)	mg/L	< 0.01	< 0.01	-	-
Cobalt (Co)	mg/L	< 0.01	< 0.01	< 0.001	< 0.001
Copper (Cu)	mg/L	< 0.01	< 0.01	< 0.002	0.006
Indium (In)	mg/L	-	-	< 0.004	< 0.004
Iron (Fe)	mg/L	0.06	< 0.01	0.02	0.002
Lead (Pb)	mg/L	< 0.1	< 0.1	< 0.01	< 0.01
Manganese (Mn)	mg/L	< 0.01	< 0.01	0.001	< 0.001
Mercury (Hg)	mg/L	< 0.001	< 0.001	< 0.0003	< 0.0003
Molybdenum (Mo)	mg/L	-	-	< 0.001	< 0.001
Nickel (Ni)	mg/L	< 0.01	< 0.01	< 0.003	< 0.003
Phosphorus (P)	mg/L	-	-	< 0.04	< 0.04
Selenium (Se)	mg/L	< 0.01	< 0.01	< 0.0001	< 0.0001
Silicon (Si)	mg/L	-	-	< 0.007	< 0.006
Silver (Ag)	mg/L	-	-	< 0.004	< 0.004
Strontium (Sr)	mg/L	-	-	< 0.001	0.002
Thallium (Tl)	mg/L	-	-	< 0.009	< 0.009
Tellurium (Te)	mg/L	-	-	< 0.012	-
Thorium (Th)	mg/L	< 0.01	< 0.01	-	< 0.012
Tin (Sn)	mg/L	0.03	< 0.01	< 0.02	< 0.02
Titanium (Ti)	mg/L	-	-	< 0.001	< 0.001
Uranium (U)	mg/L	< 0.2	< 0.2	< 0.004	< 0.004
Vanadium (V)	mg/L	< 0.01	< 0.01	0.002	< 0.002
Zinc (Zn)	mg/L	-	-	< 0.005	0.01
Zirconium (Zr)	mg/L	0.08	< 0.01	< 0.001	< 0.001
Biological Parameters					
Total coliforms	CFU/100 ml	460	150	< 3	< 3
Organics					
Oil and grease	mg/L	< 0.2	< 0.2	< 0.2	7.8
Biochemical oxygen demand (BOD)	mg/L	-	-	0.4	-
Chemical oxygen demand (COD)	mg/L	-	-	48	-

Note: - = Data not available.

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VOLUME I

APPENDIX 9.1

ATTACHMENT 1

THE 1996 TO 1998 WATER QUALITY SURVEY AT THE MINE SITE

Introduction

Water quality sampling was completed between 1996 and 1998 by Phelps Dodge within the area of the mine. The following sections briefly present the methods and results of the field and QA/QC procedures for this historical sampling campaign.

Sampling Methods and Results

Surface water quality sampling locations are labelled as SWQ-1 through SWQ-16 and are presented in Figure 1. Water quality samples collected from surface water features around the mine area were analyzed for the parameters listed in Table 1.

Samples of surface water from rivers, springs and seeps were taken by filling up a large clean container with sample directly from the river, spring or seep. Samplings were subdivided into individual containers consisting of filtered, unfiltered, preserved and unpreserved samples. Filtering took place using a 0.45 micrometer in-line filter and a peristaltic pump, using new Tygon® tubing for each sample. Samples were kept cool and shipped to an analytic laboratory within the standard holding times for the analyses.

Quality Assurance and Quality Control Procedures and Results

To help ensure that water quality sampling data are representative of site conditions, specific quality assurance and quality control (QA/QC) procedures were followed. These included field and laboratory control procedures.

Field quality control was ensured thorough documentation, field analyses and duplicate sample collection. The documentation procedures included:

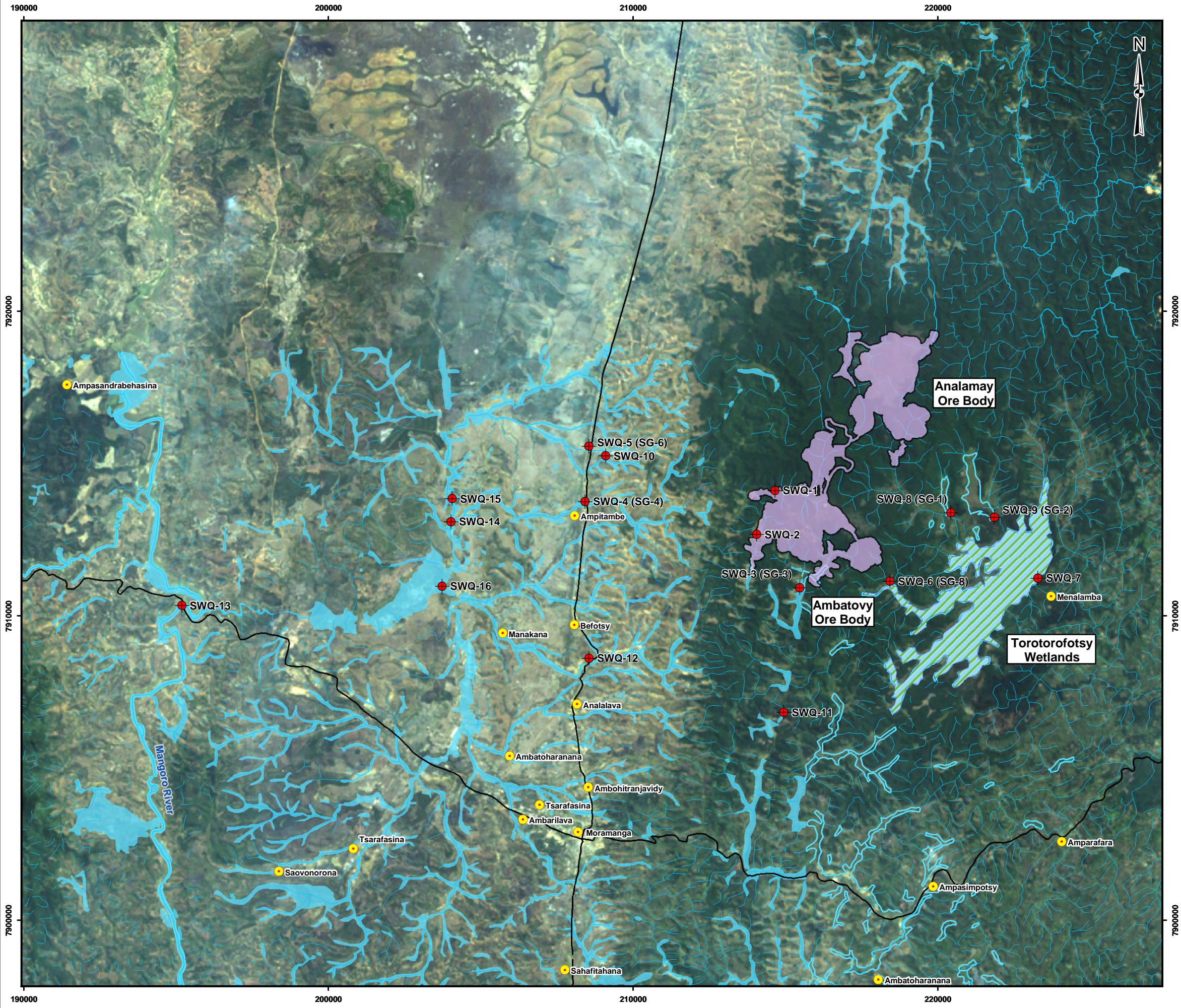
- labelling of sample bottles;
- completion of Field Report Forms;
- completion of Chain of Custody Records; and
- securing individual samples or sample coolers with chain of custody seals.

Field analyses included field measurements of pH, temperature, and specific conductance for stabilization prior to sample collection. Duplicate samples were collected to demonstrate reproducibility and reliability of laboratory results. Duplicate sample results were generally in close agreement with collected analytical samples as shown in Table 1.

Laboratory quality control was evaluated by a tour of the selected laboratory (Inspectorate M&L [PTY] Ltd.). Inspection revealed that internal laboratory QA/QC (involving periodic analytical confirmation with sample blanks, duplicates and spiked samples) and laboratory analytical equipment were within accepted industry standards.

To ensure that only representative samples were used for data interpretation, the charge balance error for sample results were checked to ensure that error values were less than 10 percent. Charge balance is defined as the difference between the sum of major cations and major anions in milliequivalents. Charge balance error is defined as the charge balance divided by the sum of major cations plus the sum of major anions multiplied by 100. All results had a charge balance error of less than 10%.

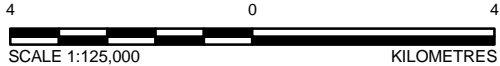
I:/2003/03-1322/03-1322-172/lrxd/Water_Quality/Fig1_HistoricalLocations.mxd



LEGEND

- HISTORICAL WATER QUALITY STATION
- POPULATION CENTRE
- ROAD
- STREAM OR RIVER
- OPEN WATER
- WETLANDS
- MINE SITE (ORE BODY)

REFERENCE
Landsat 7 Mosaic Image; Captured April/Sept. 2001
Datum: WGS 84 Projection: UTM Zone 39S




PROJECT		AMBATOVY PROJECT	
TITLE		HISTORICAL WATER QUALITY MONITORING LOCATIONS	
	PROJECT No. 03-1322-172.7100		SCALE AS SHOWN
	DESIGN	MD	12 Apr. 2005
	GIS	TN	5 Dec. 2005
	CHECK		
	REVIEW		
			FIGURE: 1

Table 1 Water Quality Results from Historical Sampling Campaign (1996 to 1998)

Site Name	Date	Laboratory pH Value	Laboratory Specific Conductivity in µS/cm	Total Suspended Solids	Total Dissolved Solids	Calcium, Ca	Magnesium, Mg	Potassium, K	Sodium, Na	Chloride, Cl	Sulfate, SO ₄	Bicarbonate, HCO ₃	Total Alkalinity as CaCO ₃	Total Hardness as CaCO ₃	Nitrate, NO ₃	Nitrite, NO ₂
SWQ-1	Sep-96	6.90	106.1	11	120	-	-	-	-	3.1	<1	56	46	-	-	-
SWQ-1	Oct-96	6.84	107.7	5	64	4.7	9.2	<0.1	4.2	3.6	<1	63	52	-	-	-
<0.01	0.01	7.00	97.6	4	98	4.6	10.0	-	2.2	2.8	1	60	49	53	0.6	<0.10
SWQ-1	Aug-97	7.57	119.5	3	103	5.5	11.0	-	1.5	3.3	2	73	60	59	1.2	0.20
SWQ-1	Sep-97	7.35	108.0	3	115	4.5	10.0	5.4	<0.1	3.2	1	62	51	52	0.2	0.10
SWQ-1	Oct-97	7.70	109.0	<1	148	6.0	11.0	<0.1	0.8	3.8	3	68	56	60	0.5	<0.10
SWQ-1	Nov-97	7.19	86.5	<1	101	4.3	7.6	4.4	2.0	2.4	3	52	43	42	0.5	0.10
SWQ-1	Feb-98	7.07	70.0	1	91	4.1	5.3	0.1	2.6	6.3	1	34	28	32	0.6	0.01
SWQ-1	Mar-98	6.87	59.6	9	69	3.1	4.2	5.2	1.0	5.3	1	28	23	25	0.8	0.01
SWQ-2	Sep-96	6.64	60.9	5	104	-	-	-	-	3.6	<1	29	24	-	-	-
SWQ-2	Oct-96	6.67	66.8	10	44	3.1	3.5	0.9	4.0	3.6	<1	34	28	-	-	-
SWQ-2	Jul-97	6.36	62.0	6	115	2.7	4.0	-	4.0	2.8	2	29	24	23	0.2	<0.10
SWQ-2	Aug-97	6.37	80.0	<1	83	4.5	5.0	-	2.6	3.3	4	44	36	32	0.7	0.10
SWQ-2	Sep-97	6.66	86.1	3	122	6.3	5.0	7.0	1.3	6.0	3	44	36	36	<0.1	0.10
SWQ-2	Oct-97	2.80	873.0	7	254	3.6	5.8	2.6	1.9	5.2	93	0	0	33	0.6	<0.10
SWQ-2	Nov-97	6.34	46.2	6	109	3.4	3.1	3.6	3.4	2.8	4	29	24	21	1.8	<0.10
SWQ-2	Feb-98	6.30	34.7	<1	65	2.7	2.0	0.7	3.2	4.8	2	17	14	15	0.2	0.01
SWQ-2	Mar-98	6.18	34.8	9	40	1.4	2.1	5.3	1.5	5.3	1	15	12	12	0.8	0.01
SWQ-3	Sep-96	6.62	81.6	2	76	-	-	-	-	3.1	7	37	30	-	-	-
SWQ-3	Oct-96	6.74	93.6	3	152	2.4	9.3	0.1	1.7	3.1	1	51	42	-	-	-
SWQ-3	Jul-97	6.50	88.8	2	123	3.0	10.3	-	2.2	2.8	2	58	48	50	0.6	<0.10
SWQ-3	Aug-97	6.75	108.3	1	91	3.3	10.5	-	1.4	2.8	2	67	55	51	0.4	0.20
SWQ-3	Sep-97	6.70	107.5	2	115	3.1	11.5	5.6	0.6	5.0	2	62	51	55	0.2	0.10
SWQ-3	Oct-97	6.90	100.4	1	142	3.3	13.4	0.1	0.6	2.3	6	63	52	63	0.4	<0.10
SWQ-3	Nov-97	6.72	72.8	1	115	2.7	7.8	4.7	1.4	2.8	4	50	41	39	0.2	<0.10
SWQ-3	Feb-98	6.66	69.6	<1	105	2.9	7.2	1.0	2.6	4.4	4	41	34	37	0.2	0.02
SWQ-3	Mar-98	6.61	59.7	10	55	2.5	5.3	5.3	0.8	4.2	2	27	22	28	0.2	0.02
SWQ-6	Sep-96	6.63	95.3	3	84					3.6	<1	51	42	-	-	-
SWQ-6	Oct-96	6.75	98.9	5	128	3.8	8.3	<0.1	1.6	3.6	<1	51	42	-	-	-
SWQ-6	Feb-98	7.05	91.8	2	87	3.9	7.9	1.0	2.4	6.1	2	49	40	42	0.3	0.02
SWQ-15	Sep-96	6.66	53.1	28	48					4.1	1	24	20	-	-	-
SWQ-15	Oct-96	6.79	50.7	37	140	2.6	2.3	0.5	5.0	3.6	3	22	18	-	-	-
SWQ-15	Nov-97	6.22	28.4	98	87	1.5	1.9	4.1	1.3	2.4	1	17	14	12	0.6	0.30
SWQ-14	Sep-96	6.59	75.1	58	80					4.6	1	37	30	-	-	-
SWQ-14	Oct-96	6.54	77.0	150	136	3.6	3.7	1.2	4.9	6.2	3	32	26	-	-	-
SWQ-14	Nov-97	6.52	54.6	32	121	3.1	3.6	6.2	2.1	2.4	2	34	28	22	0.3	0.10
SWQ-13	Sep-96	6.58	77.7	35	92					5.2	1	37	30	-	-	-
SWQ-13	Oct-96	6.52	75.8	34	152	3.0	2.1	1.7	9.9	7.0	3	31	25	-	-	-
SWQ-13	Nov-97	6.58	37.4	194	143	2.2	2.2	6.3	0.1	2.4	1	18	15	15	1.2	0.10
SWQ-12	Sep-96	6.74	24.8	23	24					3.1	<1	12	10	-	-	-
SWQ-12	Oct-96	6.59	25.8	14	48	1.9	0.7	0.2	5.0	2.6	2	15	12	-	-	-
SWQ-12	Jul-97	6.26	73.5	8	78	4.8	3.6		6.8	2.8	4	39	32	27	0.3	<0.10
SWQ-12	Aug-97	6.86	81.2	48	93	5.0	4.0		5.4	3.8	6	46	38	29	0.8	0.40
SWQ-12	Sep-97	6.48	88.2	35	121	4.7	4.5	8.3	3.8	5.1	5	44	36	30	0.2	0.30
SWQ-12	Oct-97	6.80	76.0	109	154	4.0	6.0	1.4	7.0	5.6	5	49	40	35	0.5	0.20
SWQ-12	Nov-97	6.45	23.0	154	79	1.1	1.7	5.5	0.6	1.9	3	12	10	11	0.8	0.40
SWQ-12	Feb-98	6.56	56.1	<1	69	4.3	3.0	1.0	4.0	3.6	3	32	26	23	0.3	0.02
SWQ-4	Sep-96	6.50	88.7	16	52	-	-	-	-	5.2	2	44	36	-	-	-
SWQ-4	Oct-96	6.90	86.4	21	120	4.5	4.3	0.5	4.1	4.6	1	39	32	-	-	-
SWQ-4	Jul-97	6.31	75.6	302	92	5.0	5.4	-	5.1	2.8	3	44	36	35	0.9	<0.10
SWQ-4	Aug-97	6.75	92.0	2	109	5.7	6.3	-	3.5	4.2	8	54	44	40	0.6	0.40
SWQ-4	Sep-97	6.45	91.2	31	137	4.5	5.6	6.1	2.8	6.0	5	41	34	34	0.2	0.20
SWQ-4	Oct-97	6.90	96.8	63	137	5.6	6.2	0.4	2.3	5.2	5	39	32	40	7.1	0.10

Table 1 Water Quality Results from Historical Sampling Campaign (1996 to 1998) (continued)

Site Name	Date	Laboratory pH Value	Laboratory Specific Conductivity in µS/cm	Total Suspended Solids	Total Dissolved Solids	Calcium, Ca	Magnesium, Mg	Potassium, K	Sodium, Na	Chloride, Cl	Sulfate, SO ₄	Bicarbonate, HCO ₃	Total Alkalinity as CaCO ₃	Total Hardness as CaCO ₃	Nitrate, NO ₃	Nitrite, NO ₂
SWQ-4	Nov-97	6.72	91.2	7	123	4.5	8.6	4.7	2.5	2.4	3	60	49	47	0.3	0.10
SWQ-4	Nov-97	6.65	54.2	47	70	6.2	4.0	5.2	2.0	2.8	2	34	28	32	0.3	0.20
SWQ-4	Feb-98	6.46	67.7	2	80	4.4	4.0	0.9	3.4	3.8	2	33	27	27	0.1	0.02
SWQ-4	Mar-98	6.64	60.4	11	54	4.4	4.6	6.4	2.6	9.5	3	34	28	30	0.1	0.01
SWQ-5	Sep-96	6.52	11.4	9	44	-	-	-	-	3.1	2	6	5	-	-	-
SWQ-5	Oct-96	6.67	16.2	29	88	1.5	0.5	<0.1	4.5	2.0	5	10	8	-	-	-
SWQ-5	Jul-97	6.17	31.3	6	57	2.1	2.0	-	4.0	2.6	2	21	17	14	0.3	<0.10
SWQ-5	Aug-97	6.40	35.0	2	71	2.1	2.0	-	3.3	2.4	5	24	20	14	0.4	0.30
SWQ-5	Sep-97	6.15	37.6	32	84	1.6	2.0	5.9	1.9	3.8	4	18	14.4	12	0.3	0.20
SWQ-5	Oct-97	6.50	40.7	11	123	1.6	3.2	0.2	4.6	4.2	4	20	16	17	0.3	0.10
SWQ-5	Nov-97	5.85	9.2	14	186	0.8	1.5	5.5	0.1	1.9	4	11	9	8	0.1	0.10
SWQ-5	Feb-98	6.00	12.7	2	60	1.0	1.2	0.1	2.0	3.4	1	7	6	7	0.3	0.01
SWQ-5	Mar-98	5.84	23.6	10	33	1.4	1.7	5.1	0.6	5.3	3	10	8	11	0.2	0.02
SWQ-14	Jul-97	6.18	32.4	6	39	2.6	2.3	-	3.1	0.9	4	20	16	16	0.2	<0.10
SWQ-14	Aug-97	6.34	37.0	11	68	2.3	1.8	-	3.4	2.8	6	24	20	13	0.8	0.40
SWQ-14	Sep-97	6.17	40.8	23	82	1.8	2.2	6.9	1.4	4.1	2	20	16.4	14	0.3	0.20
SWQ-14	Oct-97	6.70	46.6	130	146	2.2	3.1	0.3	4.2	5.6	6	17	14	18	0.6	0.30
SWQ-14	Nov-97	4.20	45.6	78	65	1.1	1.5	5.2	0.2	1.9	13	0	0	9	0.4	<0.10
SWQ-7	Jul-97	6.25	34.2	30	73	2.6	3.1	-	2.0	2.7	6	15	12	19	3	<0.10
SWQ-7	Aug-97	6.15	49.5	2	77	3.1	3.5	-	1.1	3.3	3	29	24	22	0.1	0.20
SWQ-7	Sep-97	6.22	48.6	6	58	2.9	3.6	6.1	0.3	4.5	2	24	20	22	0.2	0.10
SWQ-7	Oct-97	6.02	39.8	4	115	3.0	3.9	<0.1	<0.1	2.8	3	18	15	24	0.2	<0.10
SWQ-7	Feb-98	5.75	34.6	2	85	3.4	1.7	0.8	1.9	6.4	<1	15	12	15	0.2	<0.01
SWQ-7	Sep-97	6.20	48.2	4	72	2.8	3.8	4.9	<0.1	3.4	3	26	21	23	0.1	0.20
SWQ-8	Sep-96	6.54	88.2	<1	132	-	-	-	-	3.6	<1	46	38	-	-	-
SWQ-8	Oct-96	6.80	94.0	46	144	4.8	7.2	<0.1	1.8	3.6	<1	49	40	-	-	-
SWQ-8	Jul-97	7.00	76.0	4	93	4.0	6.8	-	2.0	2.0	2	43	35	38	0.3	<0.10
SWQ-8	Aug-97	7.45	95.2	4	97	5.0	7.5	-	1.8	4.2	2	56	46	44	0.3	0.20
SWQ-8	Sep-97	7.00	90.0	7	101	4.5	8.0	4.5	0.7	4.0	3	49	40	44	0.1	0.10
SWQ-8	Oct-97	7.20	80.3	1	173	5.5	8.6	<0.1	0.4	3.3	3	49	40	49	0.3	<0.10
SWQ-8	Nov-97	6.95	60.5	1	85	4.2	5.6	4.7	0.8	2.8	4	39	32	34	0.4	0.10
SWQ-8	Feb-98	6.67	72.9	4	99	7.2	5.4	0.1	1.8	4.2	4	39	32	40	0.5	0.04
SWQ-8	Mar-98	6.56	52.8	11	65	3.2	4.4	6.2	0.8	7.4	4	27	22	26	0.6	0.03
SWQ-9	Jul-97	6.32	29.1	4	53	2.3	1.6	-	2.2	2.8	4	10	8	12	0.2	<0.10
SWQ-9	Aug-97	5.94	30.4	1	70	2.5	2.0	-	1.9	2.8	5	22	18	15	0.2	0.20
SWQ-9	Sep-97	6.32	31.2	7	65	2.0	2.0	5.2	0.1	3.0	4	15	12	13	0.2	0.10
SWQ-9	Oct-97	6.03	28.8	2	129	2.5	2.5	<0.1	0.3	4.0	5	9	7	17	0.3	<0.10
SWQ-9	Nov-97	6.53	40.0	9	109	2.3	3.0	5.1	1.1	3.8	1	20	16	18	0.1	0.10
SWQ-9	Feb-98	5.89	45.2	3	115	4.6	2.4	1.3	2.0	6.3	<1	23	19	21	0.3	<0.01
SWQ-9	Mar-98	6.21	47.6	18	123	4.6	3.0	5.7	2.0	7.4	1	27	22	24	0.5	0.06
SWQ-9	Oct-97	6.00	29.8	2	115	2.2	2.9	<0.1	1.0	5.2	4	10	8	17	0.2	<0.10
SWQ-10	Jul-97	5.79	12.4	4	39	0.8	0.3	-	4.0	1.9	1	10	8	3	0.1	<0.10
SWQ-10	Aug-97	5.82	14.4	1	48	1.2	1.4	-	0.4	2.8	1	15	12	9	0.1	0.20
SWQ-10	Sep-97	6.45	19.3	5	57	0.6	1.2	4.1	<0.1	2.4	1	9	7.4	6	<0.1	0.10
SWQ-10	Oct-97	6.20	15.0	<1	80	0.9	2.0	<0.1	1.5	2.8	1	10	8	11	0.2	<0.10
SWQ-10	Feb-98	5.83	23.7	2	70	1.5	1.4	0.9	2.5	2.7	2	12	10	10	0.2	0.01
SWQ-10	Mar-98	5.76	12.8	11	25	1.5	1.3	5.2	0.7	4.2	2	10	8	9	0.5	0.01

Table 1 Water Quality Results from Historical Sampling Campaign (1996 to 1998) (continued)

Site Name	Date	Free & Saline Ammonia as N	Total Phosphate, PO ₄	Fluoride, F	Boron, B	Arsenic, As	Cadmium, Cd	Cobalt, Co	Chromium III	Chromium VI	Copper, Cu	Iron, Fe	Lead, Pb	Manganese, Mn	Mercury, Hg	Nickel, Ni	Selenium, Se	Silica, Si	Silver, Ag	Zinc, Zn
SWQ-1	Sep-96	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SWQ-1	Oct-96	-	-	0.1	-	<0.01	-	<0.01	-	-	<0.01	<0.01	<0.01	<0.01	<0.001	<0.01	-	-	-	<0.01
	0.01	<0.1	0.40	0.1	0.32	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.06	0.001			-	<0.01	<0.01
SWQ-1	Aug-97	<0.1	0.60	0.1	0.08	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	0.001	<0.01	0.01	-	<0.01	<0.01
SWQ-1	Sep-97	<0.1	0.20	0.1	0.14	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.06	<0.01	0.01	0.001	<0.01	0.03	-	<0.01	<0.01
SWQ-1	Oct-97	<0.1	0.30	0.1	0.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.11	<0.01	0.16	0.001	<0.01	0.03	9.6	<0.01	<0.01
SWQ-1	Nov-97	<0.1	<0.10	0.1	0.16	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.10	<0.01	<0.01	0.001	<0.01	<0.01	10.4	<0.01	<0.01
SWQ-1	Feb-98			0.1	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.18	<0.01	<0.01	<0.001	<0.01	0.01	7.3	<0.01	<0.01
SWQ-1	Mar-98	<0.1	<0.10	0.1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.10	<0.01	<0.01	<0.001	<0.01	0.01	5.7	<0.01	0.10
SWQ-2	Sep-96	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SWQ-2	Oct-96	-	-	0.1	-	<0.01	-	<0.01	-	-	<0.01	0.82	<0.01	<0.01	<0.001	<0.01	-	-	-	<0.01
SWQ-2	Jul-97	<0.1	0.80	0.1	0.29	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.87	<0.01	0.20	<0.001	<0.01	<0.01	-	<0.01	<0.01
SWQ-2	Aug-97	<0.1	<0.10	0.1	0.04	0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.76	<0.01	0.14	<0.001	<0.01	<0.01	-	<0.01	<0.01
SWQ-2	Sep-97	0.1	0.10	0.2	0.13	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.83	<0.01	0.26	<0.001	<0.01	0.02	-	<0.01	<0.01
SWQ-2	Oct-97	0.1	0.60	0.1	0.20	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.36	<0.01	0.23	<0.001	<0.01	0.03	7.6	<0.01	<0.01
SWQ-2	Nov-97	<0.1	<0.10	0.1	0.09	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.54	<0.01	<0.01	<0.001	<0.01	<0.01	6.0	<0.01	<0.01
SWQ-2	Feb-98			0.1	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.64	<0.01	0.07	<0.001	<0.01	0.01	4.1	<0.01	<0.01
SWQ-2	Mar-98	<0.1	<0.10	0.1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.74	<0.01	0.10	<0.001	<0.01	0.01	3.6	<0.01	0.19
SWQ-3	Sep-96	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SWQ-3	Oct-96	-	-	0.1	-	<0.01	-	<0.01	-	-	<0.01	0.62	<0.01	<0.01	<0.001	<0.01	-	-	-	<0.01
SWQ-3	Jul-97	<0.1	0.60	0.1	0.13	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.47	<0.01	0.07	<0.001	<0.01	<0.01	-	<0.01	<0.01
SWQ-3	Aug-97	<0.1	1.50	0.1	0.06	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.59	<0.01	0.05	<0.001	<0.01	0.01	-	<0.01	<0.01
SWQ-3	Sep-97	<0.1	<0.10	0.2	0.13	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.66	<0.01	0.14	<0.001	<0.01	0.02	-	<0.01	<0.01
SWQ-3	Oct-97	<0.1	<0.10	0.1	0.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.06	<0.01	0.17	<0.001	<0.01	0.03	8.5	<0.01	<0.01
SWQ-3	Nov-97	<0.1	<0.10	<0.1	0.09	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.64	<0.01	<0.01	<0.001	<0.01	<0.01	7.8	<0.01	<0.01
SWQ-3	Feb-98			0.1	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.68	<0.01	<0.01	<0.001	<0.01	0.01	7.6	<0.01	<0.01
SWQ-3	Mar-98	<0.1	<0.10	0.1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.60	<0.01	0.06	<0.001	<0.01	<0.01	5.4	<0.01	<0.01
SWQ-6	Sep-96	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SWQ-6	Oct-96	-	-	0.1	-	<0.01	-	<0.01	-	-	<0.01	0.74	<0.01	<0.01	<0.001	<0.01				<0.01
SWQ-6	Feb-98	-	-	0.1	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.67	<0.01	<0.01	<0.001	<0.01	<0.01	9.4	<0.01	<0.01
SWQ-15	Sep-96	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SWQ-15	Oct-96	-	-	0.1	-	<0.01		<0.01			<0.01	0.89	<0.01	<0.01	<0.001	<0.01	-	-	-	<0.01
SWQ-15	Nov-97	<0.1	<0.10	<0.1	0.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.75	<0.01	0.04	<0.001	<0.01	<0.01	6.2	<0.01	<0.01
SWQ-14	Sep-96	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SWQ-14	Oct-96	-	-	0.1	-	<0.01		<0.01	-	-	<0.01	0.99	<0.01	<0.01	<0.001	<0.01	-	-	-	<0.01
SWQ-14	Nov-97	<0.1	<0.10	0.1	0.11	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.81	<0.01	0.06	<0.001	<0.01	<0.01	6.7	<0.01	<0.01
SWQ-13	Sep-96	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SWQ-13	Oct-96	-	-	0.1	-	<0.01		<0.01	-	-	<0.01	1.09	<0.01	<0.01	<0.001	<0.01	-	-	-	<0.01
SWQ-13	Nov-97	<0.1	0.50	0.1	0.06	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.68	<0.01	0.09	<0.001	<0.01	<0.01	10.3	<0.01	<0.01
SWQ-12	Sep-96	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SWQ-12	Oct-96	-	-	0.1	-	<0.01		<0.01	-	-	<0.01	0.76	<0.01	<0.01	<0.001	<0.01	-	-	-	<0.01
SWQ-12	Jul-97	<0.1	0.80	0.1	0.24	<0.01	<0.01	<0.01	0.01	0.01	<0.01	1.00	<0.01	0.13	<0.001	<0.01	0.01	-	<0.01	<0.01
SWQ-12	Aug-97	<0.1	0.20	0.2	0.03	0.01	<0.01	<0.01	<0.01	0.01	<0.01	1.03	<0.01	0.08	0.002	<0.01	<0.01	-	<0.01	<0.01
SWQ-12	Sep-97	<0.1	0.20	0.2	0.14	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.64	<0.01	0.16	<0.001	<0.01	0.01	-	<0.01	<0.01
SWQ-12	Oct-97	0.4	0.60	0.1	0.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.10	<0.01	0.32	<0.001	<0.01	0.04	8.0	<0.01	<0.01
SWQ-12	Nov-97	<0.1	<0.10	0.1	0.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.80	<0.01	0.06	<0.001	<0.01	<0.01	5.4	<0.01	<0.01
SWQ-12	Feb-98	-	-	0.1	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.67	<0.01	<0.01	<0.001	<0.01	<0.01	7.0	<0.01	<0.01
SWQ-4	Sep-96	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SWQ-4	Oct-96	-	-	0.1	-	<0.01	-	<0.01	-	-	<0.01	1.57	<0.01	<0.01	<0.001	<0.01	-	-	-	<0.01
SWQ-4	Jul-97	<0.1	0.10	0.1	0.21	<0.01	<0.01	<0.01	0.08	0.01	<0.01	0.82	<0.01	0.23	<0.001	<0.01	0.01	-	<0.01	<0.01
SWQ-4	Aug-97	0.1	0.30	0.2	0.01	0.01	<0.01	<0.01	<0.01	0.01	<0.01	1.13	<0.01	<0.01	<0.001	<0.01	<0.01	-	<0.01	<0.01
SWQ-4	Sep-97	<0.1	0.20	0.2	0.20	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.25	<0.01	0.09	<0.001	<0.01	0.02	-	<0.01	<0.01
SWQ-4	Oct-97	<0.1	0.10	0.1	0.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.33	<0.01	0.20	<0.001	<0.01	0.04	8.5	<0.01	<0.01

Table 1 Water Quality Results from Historical Sampling Campaign (1996 to 1998) (continued)

Site Name	Date	Free & Saline Ammonia as N	Total Phosphate, PO ₄	Fluoride, F	Boron, B	Arsenic, As	Cadmium, Cd	Cobalt, Co	Chromium III	Chromium VI	Copper, Cu	Iron, Fe	Lead, Pb	Manganese, Mn	Mercury, Hg	Nickel, Ni	Selenium, Se	Silica, Si	Silver, Ag	Zinc, Zn
SWQ-4	Nov-97	<0.1	<0.10	<0.1	0.11	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.59	<0.01	0.06	<0.001	<0.01	<0.01	9.7	<0.01	<0.01
SWQ-4	Nov-97	<0.1	0.10	0.1	0.08	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.01	<0.01	<0.01	<0.001	<0.01	<0.01	6.8	<0.01	<0.01
SWQ-4	Feb-98			0.1	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.72	<0.01	<0.01	<0.001	<0.01	<0.01	6.9	<0.01	<0.01
SWQ-4	Mar-98	<0.1	<0.10	0.1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.51	<0.01	0.03	<0.001	<0.01	<0.01	5.9	<0.01	0.03
SWQ-5	Sep-96	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SWQ-5	Oct-96	-	-	0.1	-	<0.01	-	<0.01	-	-	<0.01	0.77	<0.01	<0.01	<0.001	<0.01	-	-	-	<0.01
SWQ-5	Jul-97	<0.1	0.10	0.1	0.24	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.86	<0.01	0.08	0.001	<0.01	0.01	-	<0.01	<0.01
SWQ-5	Aug-97	0.1	0.20	0.2	0.06	0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.69	<0.01	<0.01	0.001	<0.01	<0.01	-	<0.01	<0.01
SWQ-5	Sep-97	<0.1	0.20	0.1	0.16	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.36	<0.01	<0.01	0.001	<0.01	0.01	-	<0.01	<0.01
SWQ-5	Oct-97	<0.1	<0.10	0.1	0.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.41	<0.01	0.13	<0.001	<0.01	0.04	5.8	<0.01	<0.01
SWQ-5	Nov-97	<0.1	0.20	<0.1	0.09	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.37	<0.01	<0.01	<0.001	<0.01	<0.01	2.2	<0.01	<0.01
SWQ-5	Feb-98			0.1	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.12	<0.01	<0.01	<0.001	<0.01	<0.01	2.9	<0.01	<0.01
SWQ-5	Mar-98	<0.1	<0.10	0.1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.91	<0.01	0.11	<0.001	<0.01	<0.01	3.4	<0.01	<0.01
SWQ-14	Jul-97	<0.1	0.50	0.1	0.14	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.63	<0.01	0.08	<0.001	<0.01	0.01	-	<0.01	<0.01
SWQ-14	Aug-97	<0.1	0.90	0.1	0.07	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	2.60	<0.01	<0.01	<0.001	<0.01	<0.01	-	<0.01	<0.01
SWQ-14	Sep-97	<0.1	0.20	0.1	0.14	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.12	<0.01	<0.01	<0.001	<0.01	0.02	-	<0.01	<0.01
SWQ-14	Oct-97	<0.1	0.10	0.1	0.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.10	<0.01	0.16	<0.001	<0.01	0.04	6.8	<0.01	<0.01
SWQ-14	Nov-97	<0.1	<0.10	<0.1	0.09	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.82	<0.01	0.11	<0.001	<0.01	<0.01	2.6	<0.01	<0.01
SWQ-7	Jul-97	<0.1	0.05	0.1	0.36	<0.01	<0.01	<0.01	0.09	0.13	<0.01	0.41	<0.01	0.10	<0.001	<0.01	<0.01	-	<0.01	<0.01
SWQ-7	Aug-97	<0.1	1.90	0.1	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.49	<0.01	0.04	<0.001	<0.01	0.01	-	<0.01	<0.01
SWQ-7	Sep-97	<0.1	0.20	0.2	0.14	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.46	<0.01	0.07	<0.001	<0.01	0.02	-	<0.01	<0.01
SWQ-7	Oct-97	0.1	0.10	0.2	0.30	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.56	<0.01	0.12	<0.001	<0.01	0.01	2.8	<0.01	<0.01
SWQ-7	Feb-98			0.1	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.95	<0.01	<0.01	<0.001	<0.01	<0.01	3.5	<0.01	<0.01
SWQ-7	Sep-97	0.1	0.10	0.1	0.14	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.55	<0.01	0.06	<0.001	<0.01	0.02		<0.01	<0.01
SWQ-8	Sep-96	-	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SWQ-8	Oct-96	-	-	0.1	-	<0.01		<0.01	-	-	<0.01	0.18	<0.01	<0.01	<0.001	<0.01	-	-	-	<0.01
SWQ-8	Jul-97	<0.1	<0.10	0.2	0.19	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.42	<0.01	0.13	0.005	<0.01	<0.01	-	<0.01	<0.01
SWQ-8	Aug-97	<0.1	<0.10	0.2	0.06	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.38	<0.01	<0.01	<0.001	<0.01	<0.01	-	<0.01	<0.01
SWQ-8	Sep-97	<0.1	0.20	0.2	0.12	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.50	<0.01	<0.01	<0.001	<0.01	0.02	-	<0.01	<0.01
SWQ-8	Oct-97	<0.1	<0.10	0.1	0.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.66	<0.01	0.12	<0.001	<0.01	0.02	7.4	<0.01	<0.01
SWQ-8	Nov-97	<0.1	<0.10	<0.1	0.09	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.35	<0.01	0.08	<0.001	<0.01	<0.01	6.4	<0.01	<0.01
SWQ-8	Feb-98			0.1	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.04	<0.01	0.07	<0.001	<0.01	0.01	7.1	<0.01	<0.01
SWQ-8	Mar-98	<0.1	<0.10	0.1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.31	<0.01	0.15	<0.001	<0.01	<0.01	5.0	<0.01	0.15
SWQ-9	Jul-97	<0.1	<0.10	0.1	0.13	<0.01	<0.01	<0.01	0.03	0.14	<0.01	0.37	<0.01	0.06	<0.001	<0.01	<0.01	-	<0.01	<0.01
SWQ-9	Aug-97	0.1	0.40	0.1	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.31	<0.01	<0.01	<0.001	<0.01	0.01	-	<0.01	<0.01
SWQ-9	Sep-97	0.1	0.20	0.2	0.13	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.38	<0.01	<0.01	<0.001	<0.01	0.01	-	<0.01	<0.01
SWQ-9	Oct-97	0.1	<0.10	0.1	0.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.44	<0.01	<0.01	<0.001	<0.01	0.01	3.8	<0.01	<0.01
SWQ-9	Nov-97	<0.1	0.30	<0.1	0.08	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.69	<0.01	0.06	<0.001	<0.01	<0.01	4.4	<0.01	<0.01
SWQ-9	Feb-98			0.1	0.06	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.10	<0.01	0.10	<0.001	<0.01	0.01	4.6	<0.01	<0.01
SWQ-9	Mar-98	<0.1	0.10	0.1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	4.10	<0.01	0.21	<0.001	<0.01	<0.01	3.2	<0.01	0.18
SWQ-9	Oct-97	<0.1	<0.10	0.1	0.20	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.39	<0.01	<0.01	<0.001	<0.01	0.01	3.8	<0.01	<0.01
SWQ-10	Jul-97	<0.1	<0.10	0.1	0.27	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.25	<0.01	<0.01	<0.001	<0.01	0.01	-	<0.01	<0.01
SWQ-10	Aug-97	<0.1	0.20	0.1	0.10	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.56	<0.01	<0.01	0.001	<0.01	<0.01	-	<0.01	<0.01
SWQ-10	Sep-97	0.1	0.10	0.1	0.14	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.25	<0.01	<0.01	<0.001	<0.01	0.02	-	<0.01	<0.01
SWQ-10	Oct-97	<0.1	<0.10	0.1	0.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.27	<0.01	<0.01	<0.001	<0.01	0.03	3.3	<0.01	<0.01
SWQ-10	Feb-98			0.1	0.07	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.29	<0.01	<0.01	<0.001	<0.01	<0.01	4.3	<0.01	<0.01
SWQ-10	Mar-98	<0.1	1.10	0.1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.93	<0.01	0.15	<0.001	<0.01	0.01	3.1	<0.01	0.07

Notes:
Results are expressed in mg/L where applicable.
D = Duplicate Sample.

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APPENDIX 9.1

ATTACHMENT 2

**UNIVERSAL TRANSVERSE MERCATOR (UTM) COORDINATES OF STATION
LOCATIONS**

Table 1 Universal Transverse Mercator (UTM) Coordinates of Stations

Station Name	UTM (East)	UTM (South)
003+500	219571	7914793
007+500	224152	7912028
012+100	224702	7910378
019+400	230278	7907666
042+500	240613	7915152
052+500	241492	7920933
060+100	247440	7922651
107+000	276464	7934574
136+000	190853	7942527
146+000	299667	7953150
157+700	307285	7961728
175+300	313957	7977002
179+300	316872	7980572
E3 005+150	237773	7906330
E3 011+950	242226	7906091
QESF-100	215583	7911213
QESF-101	222004	7913134
QESF-102	220816	7915373
QESF-103	220747	7913139
QESF-104	219991	7912192
QESF-105	214234	7912830
QESF-106	212758	7912748
QESF-107	216362	7911698
QESF-108	215241	7911601
QESF-109	219912	7919476
QESF-110	217109	7919156
QESF-111	218550	7910988
QESF-112	223673	7910837
QESF-113	220976	7918337
QESF-114	214686	7905909
QESF-115	195841	7910025
QESF-116	218550	7910988
QESF-117	214359	7914115
QESF-118	213050	7915130
QESF-119	222271	7911598
QESF-120	194394	7913203
QESF-121	194407	7915168
QESF-122	223273	7913025
QESF-200	323626	7987464
QESF-201	324319	7986955
QESF-202	325448	7990707
QESF-203	325028	7989435
QESF-204	324195	7991502
QESF-205	328274	7988343
QESF-206	328190	7988351
QESF-207	324742	7988463
QESF-208	327123	7990068
QESF-209	321801	7993522
QESF-210	322085	7993485
QESF-211	319575	7992329
QESF-212	328326	7990115
QESF-213	321640	7987816
QESF-214	318619	7988487
QESF-215	322441	7989196

**Table 1 Universal Transverse Mercator (UTM) Coordinates of Stations
(continued)**

Station Name	UTM (East)	UTM (South)
QESF-216	322234	7990661
QESF-217	328132	7990064
QESF-218	327026	7989110
QESF-219	327676	7990611
QESF-220	329163	7989437
QESF-221	325884	7989649
QESF-222	326230	7990095
QESF-223	326497	7990741
QESF-224	324568	7985907
QESF-225	318402	7983522
QESF-226	322788	7983298
QESF-227	322240	7983400
QESF-228	322339	7983114
QESF-230	326146	7987585
QESF-231	325533	7985784
QESF-232	327509	7986032
QESF-233	327836	7986911
SWQ-1	214649	7914122
SWQ-10	209090	7915258
SWQ-11	214940	7906830
SWQ-12	208552	7908615
SWQ-13	195184	7910347
SWQ-14	204022	7913095
SWQ-15	204057	7913851
SWQ-16	203730	7910982
SWQ-2	214050	7912679
SWQ-3	215468	7910917
SWQ-4	208418	7913759
SWQ-5	208547	7915573
SWQ-6	218430	7911135
SWQ-7	223283	7911246
SWQ-8	220420	7913394
SWQ-9	221853	7913251

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APPENDIX 9.1

ATTACHMENT 3

BACKGROUND GENERAL WATER QUALITY INFORMATION

Introduction

Baseline water quality from 2004 in surface water bodies was described in terms of key physical and chemical characteristics. This report focuses on parameters that are considered indicators of important aspects of water quality including pH, dissolved oxygen, major ions, acid sensitivity, total suspended solids (TSS), nutrients and metals. A brief description of key water quality parameters used in this report is presented below.

pH

The pH is an indication of the acidic or basic (i.e., alkaline) nature of water. Neutral water has a pH of seven. The pH of natural surface waters is commonly between six and nine. Most aquatic organisms can tolerate waters that fall within this pH range. If water becomes more acidic, the pH drops. If water becomes more alkaline, the pH increases. Acid deposition, resulting from anthropogenic air emissions, can lower the pH of surface waters.

Dissolved Oxygen

Dissolved oxygen is a measure of the amount of gaseous oxygen, (i.e., O₂) dissolved in water. Dissolved oxygen levels are governed by a balance between inputs from the surrounding air, aeration, (i.e., rapid movement), and as a product of photosynthesis and losses from chemical and biotic oxidations. The amount of oxygen available to aquatic life depends on the solubility of oxygen, which is governed by atmospheric pressure, turbulence, temperature, salinity, currents, ice-cover and biological processes (Wetzel 2001). Reduced oxygen levels can cause physiological and behavioural effects in aquatic organisms. In this report, dissolved oxygen concentrations are compared to the aquatic life guidelines.

Major Ions

Three indicators related to the concentrations of major ions in surface waters are hardness, Total Dissolved Solids (TDS) and conductance.

The toxicity of many metals declines with increasing hardness, which is a measure of the sum of calcium and magnesium concentrations. Table 1 provides a general scale of water hardness, expressed as mg/L equivalent of calcium carbonate.

Table 1 Qualitative Scale of Water Hardness Based on Calcium Carbonate

Hardness Scale	Calcium Carbonate (mg/L)
Very soft (<i>low</i>)	0–30 (<28)
Soft	31–60
Moderately soft (<i>relatively low</i>)	61–120 (28–120)
Hard	121–180
Very hard	>180

Note: Italics indicate definitions of hardness by Mitchell and Prepas (1990).
Sources: McNeely et al. (1979); Mitchell and Prepas (1990).

Another measure of the amount of major ions in water is TDS, which is the concentration of dissolved salts remaining after filtered water is evaporated at 180°C. Total Dissolved Solids in excess of 1,000 mg/L can adversely affect freshwater aquatic life (Hart et al. 1990). Table 2 provides a scale of TDS and salinity.

Table 2 Qualitative Scale of Salinity Based on Total Dissolved Solids

Salinity Scale	Total Dissolved Solids (mg/L)	Salinity (parts per thousand)
Fresh water	<500	<0.5
Slightly saline	500–1,000	0.5–1
Moderately saline	1,000–5,000	1–5
Saline	>5,000	>5

Source: Mitchell and Prepas (1990).

Electrical conductance is another measure of the total quantity of dissolved ions in water. Conductance and TDS are strongly correlated. Table 3 provides the qualitative scales for TDS and conductance in fresh water.

Table 3 Qualitative Scales of Total Dissolved Solids and Conductance in Fresh Water

Description	Total Dissolved Solids (mg/L)	Conductance (µS/cm)
Low	≤100	≤165
Moderately low	101–200	166–330
Moderate	201–300	331–500
Moderately high	301–400	501–665
High	401–500	666–830
Very high	>500	>830

Acid Sensitivity

Alkalinity is a measure of the acid neutralizing capacity (ANC) of water and provides an indication of the sensitivity of water to acid deposition. Saffran and Trew (1996) presented a scale of lake sensitivity to acidification based on alkalinity (see Table 4).

Table 4 Qualitative Scale of Lake Acid Sensitivity

Acid Sensitivity	Alkalinity	
	(mg/L CaCO ₃)	(meq/L)
High	0–10	0–200
Moderate	10–20	200–400
Low	20–40	400–800
Least	>40	>800

Source: Saffran and Trew (1996).

The commonly accepted categories of acid sensitivity for streams, provided in Table 5, are based on alkalinity and ANC. An annual average value of 150 µeq/L has also been used as a cut-off point for designating streams as acid sensitive, based on effects on fish populations in streams with ANC above 150 µeq/L (Brewer et al. 2000).

Table 5 Qualitative Scale of Stream Acid Sensitivity

Acid Sensitivity	Alkalinity (mg/L as CaCO ₃)	Acid Neutralizing Capacity (meq/L)
Acidic	<0	<0
Highly sensitive	0–2.5	0–50
Sensitive	2.6–10	51–200
Not sensitive	>10	>200

Source: Boward et al. (1999).

Total Suspended Solids

Total suspended solids, also referred to as total suspended sediment, includes all particles suspended in the water column that would be removed using a filter with pore sizes of 0.45 microns. An increase in TSS can result in stress to aquatic animals. Total suspended solids concentrations below 25 mg/L are usually not considered harmful to aquatic life (Department of Fisheries and Oceans [DFO] and Department of Environment [Environment Canada] [DOE] 1983; European Inland Fisheries Advisory Commission [EIFAC] 1965; United States Environment Protection Agency [U.S. EPA] 1973). The nature and severity of adverse effects of TSS is a function of concentration and exposure. Most aquatic organisms can withstand high levels of TSS for short periods and low levels for long periods (Newcombe and MacDonald 1991). Total suspended solids categories used in this report are:

- low – less than 10 mg/L;
- moderate – 10 to 25 mg/L; and
- high – greater than 25 mg/L.

Nutrients

Nutrients include nitrogen and phosphorus compounds that are required in small quantities for plant growth. In general, the biological productivity of fresh water is limited by phosphorus, meaning that phosphorus is the nutrient in the shortest supply. Total phosphorus concentrations can range from 1 µg/L in unproductive waters to greater than 100 µg/L in highly productive waters. Table 6 presents a trophic-based (i.e., nutrient-related), classification of lakes and rivers in relation to phosphorus concentrations.

Table 6 Trophic Classification of Lakes and Rivers Based on Total Phosphorus Concentration

Trophic Status	Total Phosphorus (mg/L)	
	Lakes ^(a)	Rivers and Streams ^(b)
Ultra-oligotrophic (very nutrient-poor)	<0.004	–
Oligotrophic (nutrient-poor)	0.004–0.01	<0.025
Mesotrophic (containing a moderate level of nutrients)	0.01–0.02	0.025–0.075
Meso-eutrophic (containing moderate to high level of nutrients)	0.02–0.035	–
Eutrophic (nutrient rich)	0.035–0.1	>0.075
Hypereutrophic (very nutrient rich)	>0.1	–

Note:

^(a) Vollenweider and Kerekes (1982).

^(b) Dodds et al. (1998).

– = Not applicable.

Metals

Metals occur naturally in small quantities, i.e., less than 1 mg/L, in surface waters. Higher metal concentrations are usually associated with suspended sediments and tend to settle out. Elevated levels of metals can affect aquatic organisms. The level at which metals are toxic varies by metal and can be dependent on a number of factors including hardness, dissolved organic matter (DOC), pH and redox conditions. Dissolved metals refer to the portion of the metals that are dissolved in the water column (i.e., would not be filtered out in analysis) and tend to be more bio-available than metals adsorbed to particulates. Total metals refers to the sum of dissolve and particulate metals and is the form analyzed in this report.

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VOLUME I: PHYSICAL APPENDICES
SECTION 9.2: WATER QUALITY EA APPENDIX

ATTACHMENT 1 - MINE

Submitted to:
Dynatec Corporation

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9.2 INTRODUCTION

This appendix presents additional information used or generated in Volume B, Section 3.9 (Water Quality Section of the Mine Environmental Assessment [EA]) and includes:

- formulas and inputs values used in sediment quality modelling;
- detailed results from the mine water quality modelling; and,
- detailed results from the mine sediment quality modelling.

9.2.1 Sediment Modelling

Equations for calculating substance concentration in benthic sediment (USEPA 1999) are given as:

$$f_{bs} = 1 - \frac{(1 + Kd_{sw} \cdot TSS \cdot 10^{-6}) \cdot d_{wc} / (d_{wc} + d_{bs})}{(1 + Kd_{sw} \cdot TSS \cdot 10^{-6}) \cdot d_{wc} / (d_{wc} + d_{bs}) + (\theta_{bs} + Kd_{bs} \cdot BS) \cdot d_{bs} / (d_{wc} + d_{bs})}$$

$$C_{sed} = f_{bs} \cdot C_{wtot} \cdot \left(\frac{Kd_{bs}}{\theta_{bs} + Kd_{bs} \cdot BS} \right) \cdot \left(\frac{d_{wc} + d_{bs}}{d_{bs}} \right)$$

where:

- f_{bs} = fraction of total waterbody substance concentration in benthic sediment (unitless);
- Kd_{sw} = suspended sediment/surface water partition coefficient (L water/kg suspended sediment);
- TSS = total suspended solids concentration (mg/L);
- 10^{-6} = units conversion factor (kg/mg);
- θ_{bs} = bed sediment porosity (L_{water}/L_{sediment});
- Kd_{bs} = bed sediment/sediment pore water partition coefficient (L water/kg bottom sediment);
- BS = benthic solids concentration (g/cm³ [equivalent to kg/L]);
- d_{wc} = depth of water column (m);
- d_{bs} = depth of upper benthic sediment layer (m);
- C_{sed} = substance concentration in bed sediment (mg substance/kg sediment);
- C_{wtot} = total water body substance concentration, including water column and bed sediment (mg substance/L water body);

Input values for watercourse characteristics and partition coefficients are provided in Tables 9.2-1 and 9.2-2, respectively.

Table 9.2-1 Characteristics of Watercourses Used for Sediment Modelling

Parameter	Units	Value for Mine Area
pH	-	7 ^(a)
water depth	m	0.7 ^(b)
benthic sediment depth	m	0.03 ^(c)
total suspended solids	mg/L	4 ^(a)
bed sediment porosity	L water/L sediment	1 ^(c)
benthic sediment density	kg/L	1 ^(c)

(a) Estimated based on observed source water values.

(b) Estimated based on predicted water levels (Volume B, Section 3.8).

(c) Default value used because predicted values were not available for this parameter and varying this input does not result in substantial changes in sediment concentration predictions.

Table 9.2-2 Partition Coefficients Used for Sediment Modelling

Substance	Suspended Solids - Surface Water, $K_{d_{sw}}$ (L/kg) ^(a)	Bed sediment - Sediment Pore Water, $K_{d_{bs}}$ (L/kg) ^(a)
aluminum	1.5×10^3	1.5×10^3
antimony	45	45
arsenic	29	29
barium	41	41
boron	3	3
cadmium	75	75
chromium	1.8×10^6	1.8×10^6
cobalt	45	45
copper	1.0×10^4	1.0×10^4
lead	900	900
manganese	19.4	19.4
mercury	3.0×10^3	3.0×10^3
nickel	65	65
selenium	5	5
thallium	71	71
vanadium	62	62
zinc	62	62
iron	25.1	25.1

(a) USEPA 1999. Screening Level Ecological risk Assessment Protocol for Hazardous Waste Combustion facilities. Volume 1. Solid Waste and Emergency Response (5305W). USEPA, EPA530-D-99-001A.

9.2.2 Water Quality Results

Tables 9.2-3 to 9.2-12 present the detailed water quality modelling results for the mine area.

9.2.3 Sediment Quality Results

Table 9.2-13 presents the detailed sediment quality modelling results for the mine area.

Table 9.2-3 Water Quality Results From Mine Area at Clarification Pond Outlets

Antsahalava River Outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	23	21	23	22	32	33	23	21	23	22	32	33	23	21	23	22	32	45	31	27	31	30	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.12	0.10	0.11	0.11	0.17	0.18	0.12	0.10	0.11	0.11	0.17	0.18	0.12	0.10	0.11	0.11	0.17	0.05	0.03	0.03	0.03	0.03	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.5	1.5	1.5	1.5	1.4	1.4	1.5	1.5	1.5	1.5	1.4	1.4	1.5	1.5	1.5	1.5	1.4	1.6	1.6	1.7	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	3.2	2.7	2.6	2.7	2.6	3.2	3.2	2.7	2.6	2.7	2.6	3.2	3.2	2.7	2.6	2.7	2.6	3.2	2.6	2.3	2.2	2.3	2.3	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05
Magnesium (Mg)	mg/L	-	-	7	5	4	5	5	7	7	5	4	5	5	7	7	5	4	5	5	7	8	6	5	6	6	8
Potassium (K)	mg/L	-	-	0.9	0.6	0.5	0.6	0.6	0.9	0.9	0.6	0.5	0.6	0.6	0.9	0.9	0.6	0.5	0.6	0.6	0.9	0.8	0.5	0.5	0.5	0.5	0.7
Sodium (Na)	mg/L	-	-	1.3	1.9	2.2	2.0	2.1	1.3	1.3	1.9	2.2	2.0	2.1	1.3	1.3	1.9	2.2	2.0	2.1	1.3	2.8	2.9	3.1	2.9	3.0	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	3	2	3	2	2	2	3	2	3	2	2	2	3	2	3	2	1	2	3	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0352	0.0310	0.0350	0.0336	0.0496	0.0500	0.0352	0.0310	0.0350	0.0336	0.0496	0.0500	0.0352	0.0310	0.0350	0.0336	0.0496	0.0003	0.0028	0.0033	0.0030	0.0031	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0049	0.0048	0.0049	0.0049	0.0054	0.0055	0.0049	0.0048	0.0049	0.0049	0.0054	0.0055	0.0049	0.0048	0.0049	0.0049	0.0054	0.0002	0.0014	0.0019	0.0015	0.0016	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.083	0.110	0.086	0.095	0.025	0.025	0.083	0.110	0.086	0.095	0.025	0.025	0.083	0.110	0.086	0.095	0.025	0.013	0.075	0.103	0.078	0.087	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.005	0.005	0.005	0.005	0.005	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0035	0.0031	0.0035	0.0034	0.0050	0.0050	0.0035	0.0031	0.0035	0.0034	0.0050	0.0050	0.0035	0.0031	0.0035	0.0034	0.0050	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.023	0.024	0.022	0.022	0.006	0.006	0.023	0.024	0.022	0.022	0.006	0.006	0.023	0.024	0.022	0.022	0.006	0.008	0.024	0.025	0.023	0.023	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.003	0.004	0.003	0.005	0.005	0.004	0.003	0.004	0.003	0.005	0.005	0.004	0.003	0.004	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005
Iron (Fe)	mg/L	-	-	1.1	0.8	0.7	0.8	0.7	1.1	1.1	0.8	0.7	0.8	0.7	1.1	1.1	0.8	0.7	0.8	0.7	1.1	1.4	1.0	0.8	0.9	0.9	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.034	0.029	0.034	0.032	0.050	0.050	0.034	0.029	0.034	0.032	0.050	0.050	0.034	0.029	0.034	0.032	0.050	0.005	0.005	0.004	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.05	0.04	0.05	0.05	0.07	0.07	0.05	0.04	0.05	0.05	0.07	0.07	0.05	0.04	0.05	0.05	0.07	0.06	0.05	0.04	0.05	0.04	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0004	0.0003	0.0004	0.0004	0.0005	0.0005	0.0004	0.0003	0.0004	0.0004	0.0005	0.0005	0.0004	0.0003	0.0004	0.0004	0.0005	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0052	0.0071	0.0054	0.0060	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.005	0.006	0.006	0.008	0.008	0.006	0.005	0.006	0.006	0.008	0.008	0.006	0.005	0.006	0.006	0.008	0.008	0.006	0.005	0.006	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0046	0.0046	0.0046	0.0046	0.0050	0.0050	0.0046	0.0046	0.0046	0.0046	0.0050	0.0050	0.0046	0.0046	0.0046	0.0046	0.0050	0.0001	0.0014	0.0019	0.0015	0.0016	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	6	5	6	6	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.007	0.007	0.007	0.007	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.070	0.062	0.070	0.067	0.099	0.100	0.070	0.062	0.070	0.067	0.099	0.100	0.070	0.062	0.070	0.067	0.099	0.002	0.007	0.007	0.007	0.007	0.002
Vanadium (V)	mg/L	-	-	0.005	0.004	0.003	0.004	0.003	0.005	0.005	0.004	0.003	0.004	0.003	0.005	0.005	0.004	0.003	0.004	0.003	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.012	0.012	0.012	0.012	0.014	0.014	0.012	0.012	0.012	0.012	0.014	0.014	0.012	0.012	0.012	0.012	0.014	0.003	0.005	0.006	0.005	0.005	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-3 Water Quality Results From Mine Area at Clarification Pond Outlets (continued)

Sahaviara River Outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	20	20	15	18	32	33	20	20	15	18	32	33	20	20	15	18	32	45	26	27	20	24	43
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.10	0.10	0.07	0.09	0.17	0.18	0.10	0.10	0.07	0.09	0.17	0.18	0.10	0.10	0.07	0.09	0.17	0.05	0.03	0.03	0.02	0.03	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.3	1.3	1.4	1.3	1.3	1.4	1.3	1.3	1.4	1.3	1.3	1.4	1.3	1.3	1.4	1.3	1.3	1.6	1.4	1.4	1.5	1.5	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.04	0.04	0.03	0.04	0.05	0.05	0.04	0.04	0.03	0.04	0.05	0.05	0.04	0.04	0.03	0.04	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	1	2	2	2	2	2	1	2	2	2	2	2	1	2	2	4	3	3	2	2	4
Chloride (Cl)	mg/L	-	-	3.2	2.3	2.3	2.1	2.3	3.1	3.2	2.3	2.3	2.1	2.3	3.1	3.2	2.3	2.3	2.1	2.3	3.1	2.6	2.0	2.0	1.9	2.0	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	4	4	3	4	7	7	4	4	3	4	7	7	4	4	3	4	7	8	5	5	4	4	8
Potassium (K)	mg/L	-	-	0.9	0.5	0.5	0.4	0.5	0.9	0.9	0.5	0.5	0.4	0.5	0.9	0.9	0.5	0.5	0.4	0.5	0.9	0.8	0.5	0.5	0.4	0.4	0.7
Sodium (Na)	mg/L	-	-	1.3	1.7	1.7	2.3	2.0	1.2	1.3	1.7	1.7	2.3	2.0	1.2	1.3	1.7	1.7	2.3	2.0	1.2	2.8	2.5	2.5	2.9	2.7	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	3	2	1	2	2	2	3	2	1	2	2	2	3	2	1	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.01	0.02	0.02	0.03	0.02	0.02	0.01	0.02	0.02	0.03	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0301	0.0303	0.0228	0.0274	0.0486	0.0500	0.0301	0.0303	0.0228	0.0274	0.0486	0.0500	0.0301	0.0303	0.0228	0.0274	0.0486	0.0003	0.0026	0.0024	0.0030	0.0026	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0042	0.0042	0.0042	0.0043	0.0053	0.0055	0.0042	0.0042	0.0042	0.0043	0.0053	0.0055	0.0042	0.0042	0.0042	0.0043	0.0053	0.0002	0.0013	0.0013	0.0021	0.0016	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.076	0.075	0.124	0.097	0.024	0.025	0.076	0.075	0.124	0.097	0.024	0.025	0.076	0.075	0.124	0.097	0.024	0.013	0.069	0.068	0.119	0.091	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.005	0.005	0.005	0.005	0.006	0.007	0.005	0.005	0.005	0.005	0.006	0.007	0.005	0.005	0.005	0.005	0.006	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0030	0.0030	0.0023	0.0027	0.0049	0.0050	0.0030	0.0030	0.0023	0.0027	0.0049	0.0050	0.0030	0.0030	0.0023	0.0027	0.0049	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.017	0.017	0.020	0.018	0.006	0.006	0.017	0.017	0.020	0.018	0.006	0.006	0.017	0.017	0.020	0.018	0.006	0.008	0.018	0.018	0.020	0.019	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.003	0.003	0.002	0.003	0.005	0.005	0.003	0.003	0.002	0.003	0.005	0.005	0.003	0.003	0.002	0.003	0.005	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.003	0.003	0.002	0.003	0.005	0.005	0.003	0.003	0.002	0.003	0.005	0.005	0.003	0.003	0.002	0.003	0.005	0.005	0.003	0.003	0.002	0.003	0.005
Iron (Fe)	mg/L	-	-	1.1	0.7	0.7	0.5	0.6	1.1	1.1	0.7	0.7	0.5	0.6	1.1	1.1	0.7	0.7	0.5	0.6	1.1	1.4	0.8	0.8	0.6	0.7	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.029	0.029	0.021	0.026	0.049	0.050	0.029	0.029	0.021	0.026	0.049	0.050	0.029	0.029	0.021	0.026	0.049	0.005	0.004	0.004	0.003	0.004	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.04	0.04	0.03	0.04	0.07	0.07	0.04	0.04	0.03	0.04	0.07	0.07	0.04	0.04	0.03	0.04	0.07	0.06	0.04	0.04	0.03	0.04	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0003	0.0003	0.0002	0.0003	0.0005	0.0005	0.0003	0.0003	0.0002	0.0003	0.0005	0.0005	0.0003	0.0003	0.0002	0.0003	0.0005	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0047	0.0046	0.0080	0.0061	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.005	0.005	0.004	0.005	0.008	0.008	0.005	0.005	0.004	0.005	0.008	0.008	0.005	0.005	0.004	0.005	0.008	0.008	0.005	0.005	0.004	0.005	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0040	0.0040	0.0040	0.0041	0.0049	0.0050	0.0040	0.0040	0.0040	0.0041	0.0049	0.0050	0.0040	0.0040	0.0040	0.0041	0.0049	0.0001	0.0013	0.0013	0.0021	0.0016	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	5	5	4	5	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.006	0.006	0.007	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.060	0.061	0.046	0.055	0.097	0.100	0.060	0.061	0.046	0.055	0.097	0.100	0.060	0.061	0.046	0.055	0.097	0.002	0.006	0.006	0.007	0.006	0.002
Vanadium (V)	mg/L	-	-	0.005	0.003	0.003	0.002	0.003	0.005	0.005	0.003	0.003	0.002	0.003	0.005	0.005	0.003	0.003	0.002	0.003	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.011	0.011	0.011	0.011	0.013	0.014	0.011	0.011	0.011	0.011	0.013	0.014	0.011	0.011	0.011	0.011	0.013	0.003	0.004	0.004	0.006	0.005	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-3 Water Quality Results From Mine Area at Clarification Pond Outlets (continued)

Sahamarirana River Outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	20	20	23	23	30	33	20	20	23	23	30	33	20	20	23	23	30	45	26	26	31	31	40
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.10	0.10	0.12	0.12	0.16	0.18	0.10	0.10	0.12	0.12	0.16	0.18	0.10	0.10	0.12	0.12	0.16	0.05	0.03	0.03	0.03	0.03	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.2	1.2	1.1	1.1	1.3	1.4	1.2	1.2	1.1	1.1	1.3	1.4	1.2	1.2	1.1	1.1	1.3	1.6	1.4	1.4	1.3	1.3	1.5
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.02	0.02	0.02	0.02	0.02	0.01
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	3.2	2.2	2.3	2.4	2.4	2.9	3.2	2.2	2.3	2.4	2.4	2.9	3.2	2.2	2.3	2.4	2.4	2.9	2.6	1.9	1.9	2.0	2.0	2.4
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05
Magnesium (Mg)	mg/L	-	-	7	4	4	5	5	6	7	4	4	5	5	6	7	4	4	5	5	6	8	5	5	6	6	8
Potassium (K)	mg/L	-	-	0.9	0.5	0.5	0.6	0.6	0.8	0.9	0.5	0.5	0.6	0.6	0.8	0.9	0.5	0.5	0.6	0.6	0.8	0.8	0.4	0.5	0.5	0.5	0.7
Sodium (Na)	mg/L	-	-	1.3	1.6	1.6	1.3	1.3	1.2	1.3	1.6	1.6	1.3	1.3	1.2	1.3	1.6	1.6	1.3	1.3	1.2	2.8	2.4	2.4	2.3	2.3	2.5
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2	2	1	1	2	2	2	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0295	0.0296	0.0352	0.0346	0.0455	0.0500	0.0295	0.0296	0.0352	0.0346	0.0455	0.0500	0.0295	0.0296	0.0352	0.0346	0.0455	0.0003	0.0027	0.0027	0.0021	0.0021	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0041	0.0041	0.0042	0.0042	0.0050	0.0055	0.0041	0.0041	0.0042	0.0042	0.0050	0.0055	0.0041	0.0041	0.0042	0.0042	0.0050	0.0002	0.0012	0.0013	0.0007	0.0007	0.0001
Barium (Ba)	mg/L	0.7	-	0.025	0.066	0.069	0.041	0.045	0.023	0.025	0.066	0.069	0.041	0.045	0.023	0.025	0.066	0.069	0.041	0.045	0.023	0.013	0.060	0.062	0.033	0.037	0.012
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.005	0.005	0.005	0.005	0.006	0.007	0.005	0.005	0.005	0.005	0.006	0.007	0.005	0.005	0.005	0.005	0.006	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0030	0.0030	0.0035	0.0035	0.0045	0.0050	0.0030	0.0030	0.0035	0.0035	0.0045	0.0050	0.0030	0.0030	0.0035	0.0035	0.0045	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.025	0.024	0.012	0.009	0.006	0.006	0.025	0.024	0.012	0.009	0.006	0.006	0.025	0.024	0.012	0.009	0.006	0.008	0.026	0.025	0.013	0.010	0.007
Cobalt (Co)	mg/L	-	-	0.005	0.003	0.003	0.004	0.003	0.005	0.005	0.003	0.003	0.004	0.003	0.005	0.005	0.003	0.003	0.004	0.003	0.005	0.002	0.001	0.001	0.001	0.001	0.001
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.003	0.003	0.004	0.003	0.005	0.005	0.003	0.003	0.004	0.003	0.005	0.005	0.003	0.003	0.004	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.004
Iron (Fe)	mg/L	-	-	1.1	0.7	0.7	0.8	0.8	1.0	1.1	0.7	0.7	0.8	0.8	1.0	1.1	0.7	0.7	0.8	0.8	1.0	1.4	0.8	0.8	1.0	1.0	1.3
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.029	0.029	0.035	0.034	0.045	0.050	0.029	0.029	0.035	0.034	0.045	0.050	0.029	0.029	0.035	0.034	0.045	0.005	0.004	0.004	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.04	0.04	0.05	0.05	0.07	0.07	0.04	0.04	0.05	0.05	0.07	0.07	0.04	0.04	0.05	0.05	0.07	0.06	0.04	0.04	0.05	0.04	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0003	0.0003	0.0004	0.0004	0.0005	0.0005	0.0003	0.0003	0.0004	0.0004	0.0005	0.0005	0.0003	0.0003	0.0004	0.0004	0.0005	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0044	0.0045	0.0021	0.0023	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.005	0.005	0.006	0.006	0.007	0.008	0.005	0.005	0.006	0.006	0.007	0.008	0.005	0.005	0.006	0.006	0.007	0.008	0.005	0.005	0.006	0.005	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0039	0.0039	0.0039	0.0039	0.0045	0.0050	0.0039	0.0039	0.0039	0.0039	0.0045	0.0050	0.0039	0.0039	0.0039	0.0039	0.0045	0.0001	0.0012	0.0013	0.0006	0.0007	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	5	5	6	6	8
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.006	0.006	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.059	0.059	0.070	0.069	0.091	0.100	0.059	0.059	0.070	0.069	0.091	0.100	0.059	0.059	0.070	0.069	0.091	0.002	0.006	0.006	0.005	0.005	0.002
Vanadium (V)	mg/L	-	-	0.005	0.003	0.003	0.004	0.004	0.005	0.005	0.003	0.003	0.004	0.004	0.005	0.005	0.003	0.003	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.010	0.010	0.011	0.010	0.013	0.014	0.010	0.010	0.011	0.010	0.013	0.014	0.010	0.010	0.011	0.010	0.013	0.003	0.004	0.004	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-3 Water Quality Results From Mine Area at Clarification Pond Outlets (continued)

Torotorofotsy River Outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	33	27	28	28	32	33	33	27	29	28	32	33	33	27	29	28	32	45	45	37	41	38	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.18	0.14	0.14	0.15	0.17	0.18	0.18	0.14	0.15	0.15	0.17	0.18	0.18	0.14	0.15	0.15	0.17	0.05	0.05	0.04	0.05	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.4	1.4	1.4	1.4	1.4	1.3	1.4	1.4	1.6	1.6	1.6	1.5	1.6	1.6
Nitrite (NO2)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.2	2.9	2.9	2.9	3.2	3.2	3.2	2.9	2.9	2.9	3.2	3.2	3.2	2.9	3.0	2.9	3.2	2.6	2.6	2.4	2.5	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	7	6	6	6	7	7	7	6	6	6	7	7	7	6	6	6	7	8	8	7	8	7	8
Potassium (K)	mg/L	-	-	0.9	0.9	0.7	0.8	0.8	0.9	0.9	0.9	0.7	0.8	0.8	0.9	0.9	0.9	0.7	0.8	0.8	0.9	0.8	0.8	0.6	0.7	0.7	0.7
Sodium (Na)	mg/L	-	-	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.2	1.3	1.3	2.8	2.8	2.5	2.5	2.5	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	2	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0500	0.0421	0.0428	0.0433	0.0496	0.0500	0.0500	0.0421	0.0436	0.0433	0.0496	0.0500	0.0500	0.0421	0.0449	0.0433	0.0496	0.0003	0.0003	0.0025	0.0023	0.0023	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0055	0.0051	0.0051	0.0051	0.0054	0.0055	0.0055	0.0051	0.0051	0.0051	0.0054	0.0055	0.0055	0.0051	0.0051	0.0051	0.0054	0.0002	0.0002	0.0009	0.0004	0.0007	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.025	0.045	0.042	0.040	0.025	0.025	0.025	0.045	0.038	0.040	0.025	0.025	0.025	0.045	0.032	0.040	0.025	0.013	0.013	0.036	0.015	0.030	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0050	0.0042	0.0043	0.0043	0.0050	0.0050	0.0050	0.0042	0.0044	0.0043	0.0050	0.0050	0.0050	0.0042	0.0045	0.0043	0.0050	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.006	0.047	0.040	0.044	0.006	0.006	0.006	0.047	0.033	0.044	0.006	0.006	0.006	0.047	0.022	0.044	0.006	0.008	0.008	0.049	0.012	0.045	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.002	0.002	0.001	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.1	1.0	1.0	1.0	1.1	1.1	1.1	1.0	1.0	1.0	1.1	1.1	1.1	1.0	1.0	1.0	1.1	1.4	1.4	1.2	1.3	1.2	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.050	0.042	0.042	0.043	0.050	0.050	0.050	0.042	0.043	0.043	0.050	0.050	0.050	0.042	0.045	0.043	0.050	0.005	0.005	0.006	0.006	0.006	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.07	0.06	0.06	0.06	0.07	0.07	0.07	0.06	0.06	0.06	0.07	0.07	0.07	0.06	0.06	0.06	0.07	0.06	0.06	0.05	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0004	0.0004	0.0004	0.0005	0.0005	0.0005	0.0004	0.0004	0.0004	0.0005	0.0005	0.0005	0.0004	0.0005	0.0004	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0005	0.0027	0.0007	0.0023	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0050	0.0047	0.0047	0.0048	0.0050	0.0050	0.0050	0.0047	0.0047	0.0048	0.0050	0.0050	0.0050	0.0047	0.0047	0.0048	0.0050	0.0001	0.0001	0.0008	0.0003	0.0007	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	9	8	8	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.006	0.006	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.100	0.084	0.086	0.087	0.099	0.100	0.100	0.084	0.087	0.087	0.099	0.100	0.100	0.084	0.090	0.087	0.099	0.002	0.002	0.006	0.006	0.006	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.014	0.012	0.012	0.012	0.014	0.014	0.014	0.012	0.012	0.012	0.014	0.014	0.014	0.012	0.012	0.012	0.014	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-3 Water Quality Results From Mine Area at Clarification Pond Outlets (continued)

Sakalava River Outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	33	28	27	28	32	33	33	29	27	29	32	33	33	30	27	30	32	45	45	41	37	40	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.18	0.14	0.14	0.15	0.17	0.18	0.18	0.15	0.14	0.15	0.17	0.18	0.18	0.15	0.14	0.16	0.17	0.05	0.05	0.05	0.04	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.4	1.6	1.6	1.5	1.6	1.5	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.2	2.9	2.9	2.9	3.2	3.2	3.2	2.9	2.9	2.9	3.2	3.2	3.2	2.9	2.9	3.0	3.2	2.6	2.6	2.4	2.4	2.4	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	7	6	6	6	7	7	7	6	6	6	7	7	7	6	6	6	7	8	8	8	7	8	8
Potassium (K)	mg/L	-	-	0.9	0.9	0.8	0.7	0.8	0.9	0.9	0.9	0.8	0.7	0.8	0.9	0.9	0.9	0.8	0.7	0.8	0.9	0.8	0.8	0.7	0.6	0.7	0.7
Sodium (Na)	mg/L	-	-	1.3	1.3	1.2	1.3	1.2	1.3	1.3	1.3	1.2	1.3	1.2	1.3	1.3	1.3	1.2	1.3	1.2	1.3	2.8	2.8	2.5	2.4	2.5	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	1	1	1	2	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0500	0.0430	0.0420	0.0428	0.0493	0.0500	0.0500	0.0438	0.0420	0.0444	0.0493	0.0500	0.0500	0.0450	0.0420	0.0458	0.0493	0.0003	0.0003	0.0022	0.0021	0.0018	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0055	0.0050	0.0050	0.0050	0.0054	0.0055	0.0055	0.0050	0.0050	0.0050	0.0054	0.0055	0.0055	0.0050	0.0050	0.0050	0.0054	0.0002	0.0002	0.0004	0.0008	0.0003	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.025	0.037	0.041	0.038	0.025	0.025	0.025	0.033	0.041	0.030	0.025	0.025	0.025	0.028	0.041	0.024	0.025	0.013	0.013	0.013	0.032	0.013	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0050	0.0043	0.0042	0.0043	0.0049	0.0050	0.0050	0.0044	0.0042	0.0044	0.0049	0.0050	0.0050	0.0045	0.0042	0.0046	0.0049	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.006	0.038	0.048	0.033	0.006	0.006	0.006	0.030	0.048	0.019	0.006	0.006	0.006	0.017	0.048	0.007	0.006	0.008	0.008	0.008	0.049	0.009	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.002	0.002	0.002	0.001	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.1	1.0	1.0	1.0	1.1	1.1	1.1	1.0	1.0	1.0	1.1	1.1	1.1	1.0	1.0	1.1	1.1	1.4	1.4	1.3	1.2	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.050	0.043	0.042	0.042	0.049	0.050	0.050	0.044	0.042	0.044	0.049	0.050	0.050	0.045	0.042	0.046	0.049	0.005	0.005	0.006	0.005	0.006	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.07	0.06	0.06	0.06	0.07	0.07	0.07	0.06	0.06	0.06	0.07	0.07	0.07	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.05	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0004	0.0004	0.0004	0.0005	0.0005	0.0005	0.0004	0.0004	0.0004	0.0005	0.0005	0.0005	0.0005	0.0004	0.0005	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0005	0.0005	0.0025	0.0006	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0050	0.0047	0.0047	0.0046	0.0049	0.0050	0.0050	0.0046	0.0047	0.0046	0.0049	0.0050	0.0050	0.0046	0.0047	0.0046	0.0049	0.0001	0.0001	0.0003	0.0007	0.0002	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	9	8	8	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.006	0.006	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.100	0.086	0.084	0.086	0.099	0.100	0.100	0.088	0.084	0.089	0.099	0.100	0.100	0.090	0.084	0.092	0.099	0.002	0.002	0.006	0.005	0.005	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.014	0.012	0.012	0.012	0.014	0.014	0.014	0.012	0.012	0.012	0.014	0.014	0.014	0.012	0.012	0.012	0.014	0.003	0.003	0.002	0.003	0.002	0.002

- Notes
- 1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.
- 2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.
- 3

Based on the un-ionized portion of ammonia.
- 4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.
- 5

Based on long-term exposure.
- 6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.
- 7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.
- 8

Based on an alkalinity value of less than 60 mg/L.
- 9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).
- 10

Based on the dissolved form of this metal.
- 11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.
- 12

Based on a dissolved saturation of at least 80%.
- 13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.
- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-3 Water Quality Results From Mine Area at Clarification Pond Outlets (continued)

Ankaja River Outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	26	25	26	26	31	33	26	26	26	26	31	33	26	26	27	26	31	45	34	34	38	35	42
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.13	0.13	0.13	0.13	0.16	0.18	0.13	0.13	0.13	0.13	0.16	0.18	0.13	0.13	0.14	0.13	0.16	0.05	0.04	0.04	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.6	1.5	1.4	1.4	1.5	1.5
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	3	3	4	3	4
Chloride (Cl)	mg/L	-	-	3.2	2.7	2.7	2.7	2.7	3.0	3.2	2.7	2.7	2.7	2.7	3.0	3.2	2.7	2.7	2.7	2.7	3.0	2.6	2.3	2.2	2.3	2.3	2.5
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	6	5	6	6	7	7	6	5	6	6	7	7	6	5	6	6	7	8	7	6	7	7	8
Potassium (K)	mg/L	-	-	0.9	0.7	0.7	0.7	0.7	0.8	0.9	0.7	0.7	0.7	0.7	0.8	0.9	0.7	0.7	0.7	0.7	0.8	0.8	0.6	0.6	0.7	0.6	0.7
Sodium (Na)	mg/L	-	-	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.2	1.2	1.2	1.2	1.2	2.8	2.3	2.3	2.3	2.3	2.6
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2	2	1	1	2	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0394	0.0386	0.0399	0.0399	0.0468	0.0500	0.0394	0.0391	0.0402	0.0399	0.0468	0.0500	0.0394	0.0391	0.0406	0.0399	0.0468	0.0003	0.0024	0.0025	0.0023	0.0026	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0047	0.0047	0.0047	0.0048	0.0051	0.0055	0.0047	0.0047	0.0047	0.0048	0.0051	0.0055	0.0047	0.0047	0.0047	0.0048	0.0051	0.0002	0.0008	0.0008	0.0003	0.0008	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.041	0.042	0.038	0.039	0.023	0.025	0.041	0.040	0.037	0.039	0.023	0.025	0.041	0.040	0.035	0.039	0.023	0.013	0.032	0.031	0.012	0.030	0.012
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006	0.006	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0039	0.0039	0.0040	0.0040	0.0047	0.0050	0.0039	0.0039	0.0040	0.0040	0.0047	0.0050	0.0039	0.0039	0.0041	0.0040	0.0047	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.047	0.045	0.044	0.046	0.006	0.006	0.047	0.040	0.041	0.046	0.006	0.006	0.047	0.040	0.036	0.046	0.006	0.008	0.048	0.041	0.007	0.047	0.007
Cobalt (Co)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.002	0.001	0.001	0.002	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.004
Iron (Fe)	mg/L	-	-	1.1	0.9	0.9	0.9	0.9	1.1	1.1	0.9	0.9	0.9	0.9	1.1	1.1	0.9	0.9	0.9	0.9	1.1	1.4	1.1	1.1	1.2	1.1	1.3
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.039	0.038	0.039	0.039	0.047	0.050	0.039	0.039	0.040	0.039	0.047	0.050	0.039	0.039	0.040	0.039	0.047	0.005	0.005	0.006	0.006	0.006	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.06	0.05	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.06	0.05	0.05	0.06	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0025	0.0023	0.0004	0.0024	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.006	0.007	0.007	0.008	0.006	0.006	0.007	0.007	0.007	0.008	0.006	0.006	0.007	0.007	0.007	0.008	0.006	0.006	0.007	0.006	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0044	0.0044	0.0044	0.0044	0.0047	0.0050	0.0044	0.0043	0.0044	0.0044	0.0047	0.0050	0.0044	0.0043	0.0044	0.0044	0.0047	0.0001	0.0008	0.0007	0.0003	0.0007	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	7	7	8	7	8
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.006	0.006	0.006	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.079	0.077	0.080	0.080	0.094	0.100	0.079	0.078	0.080	0.080	0.094	0.100	0.079	0.078	0.081	0.080	0.094	0.002	0.006	0.006	0.006	0.006	0.002
Vanadium (V)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.011	0.011	0.011	0.012	0.013	0.014	0.011	0.011	0.012	0.012	0.013	0.014	0.011	0.011	0.012	0.012	0.013	0.003	0.003	0.003	0.002	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-3 Water Quality Results From Mine Area at Clarification Pond Outlets (continued)

Antsahalava River Outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	31	27	31	30	44	45	31	27	31	30	44	45	31	27	31	30	44	45	31	27	31	30	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.03	0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.03	0.03	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	2.6	2.3	2.2	2.3	2.3	2.6	2.6	2.3	2.2	2.3	2.3	2.6	2.6	2.3	2.2	2.3	2.3	2.6	2.6	2.3	2.2	2.3	2.3	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05
Magnesium (Mg)	mg/L	-	-	8	6	5	6	6	8	8	6	5	6	6	8	8	6	5	6	6	8	8	6	5	6	6	8
Potassium (K)	mg/L	-	-	0.8	0.5	0.5	0.5	0.5	0.7	0.8	0.5	0.5	0.5	0.5	0.7	0.8	0.5	0.5	0.5	0.5	0.7	0.8	0.5	0.5	0.5	0.5	0.7
Sodium (Na)	mg/L	-	-	2.8	2.9	3.1	2.9	3.0	2.7	2.8	2.9	3.1	2.9	3.0	2.7	2.8	2.9	3.1	2.9	3.0	2.7	2.8	2.9	3.1	2.9	3.0	2.7
Sulphate (SO ₄)	mg/L	-	-	1	2	3	2	2	1	1	2	3	2	2	1	1	2	3	2	2	1	1	2	3	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0028	0.0033	0.0030	0.0031	0.0003	0.0003	0.0028	0.0033	0.0030	0.0031	0.0003	0.0003	0.0028	0.0033	0.0030	0.0031	0.0003	0.0003	0.0028	0.0033	0.0030	0.0031	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0014	0.0019	0.0015	0.0016	0.0002	0.0002	0.0014	0.0019	0.0015	0.0016	0.0002	0.0002	0.0014	0.0019	0.0015	0.0016	0.0002	0.0002	0.0014	0.0019	0.0015	0.0016	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.075	0.103	0.078	0.087	0.013	0.013	0.075	0.103	0.078	0.087	0.013	0.013	0.075	0.103	0.078	0.087	0.013	0.013	0.075	0.103	0.078	0.087	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.024	0.025	0.023	0.023	0.008	0.008	0.024	0.025	0.023	0.023	0.008	0.008	0.024	0.025	0.023	0.023	0.008	0.008	0.024	0.025	0.023	0.023	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005
Iron (Fe)	mg/L	-	-	1.4	1.0	0.8	0.9	0.9	1.4	1.4	1.0	0.8	0.9	0.9	1.4	1.4	1.0	0.8	0.9	0.9	1.4	1.4	1.0	0.8	0.9	0.9	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.04	0.05	0.04	0.06	0.06	0.05	0.04	0.05	0.04	0.06	0.06	0.05	0.04	0.05	0.04	0.06	0.06	0.05	0.04	0.05	0.04	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0052	0.0071	0.0054	0.0060	0.0005	0.0005	0.0052	0.0071	0.0054	0.0060	0.0005	0.0005	0.0052	0.0071	0.0054	0.0060	0.0005	0.0005	0.0052	0.0071	0.0054	0.0060	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.005	0.006	0.006	0.008	0.008	0.006	0.005	0.006	0.006	0.008	0.008	0.006	0.005	0.006	0.006	0.008	0.008	0.006	0.005	0.006	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0014	0.0019	0.0015	0.0016	0.0001	0.0001	0.0014	0.0019	0.0015	0.0016	0.0001	0.0001	0.0014	0.0019	0.0015	0.0016	0.0001	0.0001	0.0014	0.0019	0.0015	0.0016	0.0001
Silicon (Si)	mg/L	-	-	9	6	5	6	6	9	9	6	5	6	6	9	9	6	5	6	6	9	9	6	5	6	6	9
Thallium (Tl)	mg/L	-	-	0.005	0.007	0.007	0.007	0.007	0.004	0.005	0.007	0.007	0.007	0.007	0.004	0.005	0.007	0.007	0.007	0.007	0.004	0.005	0.007	0.007	0.007	0.007	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.007	0.007	0.007	0.007	0.002	0.002	0.007	0.007	0.007	0.007	0.002	0.002	0.007	0.007	0.007	0.007	0.002	0.002	0.007	0.007	0.007	0.007	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.005	0.006	0.005	0.005	0.002	0.003	0.005	0.006	0.005	0.005	0.002	0.003	0.005	0.006	0.005	0.005	0.002	0.003	0.005	0.006	0.005	0.005	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-3 Water Quality Results From Mine Area at Clarification Pond Outlets (continued)

Sahaviara River Outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	26	27	20	24	43	45	26	27	20	24	43	45	26	27	20	24	43	45	26	27	20	24	43
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.03	0.03	0.02	0.03	0.05	0.05	0.03	0.03	0.02	0.03	0.05	0.05	0.03	0.03	0.02	0.03	0.05	0.05	0.03	0.03	0.02	0.03	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.4	1.4	1.5	1.5	1.6	1.6	1.4	1.4	1.5	1.5	1.6	1.6	1.4	1.4	1.5	1.5	1.6	1.6	1.4	1.4	1.5	1.5	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	3	3	2	2	4	4	3	3	2	2	4	4	3	3	2	2	4	4	3	3	2	2	4
Chloride (Cl)	mg/L	-	-	2.6	2.0	2.0	1.9	2.0	2.6	2.6	2.0	2.0	1.9	2.0	2.6	2.6	2.0	2.0	1.9	2.0	2.6	2.6	2.0	2.0	1.9	2.0	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	5	5	4	4	8	8	5	5	4	4	8	8	5	5	4	4	8	8	5	5	4	4	8
Potassium (K)	mg/L	-	-	0.8	0.5	0.5	0.4	0.4	0.7	0.8	0.5	0.5	0.4	0.4	0.7	0.8	0.5	0.5	0.4	0.4	0.7	0.8	0.5	0.5	0.4	0.4	0.7
Sodium (Na)	mg/L	-	-	2.8	2.5	2.5	2.9	2.7	2.7	2.8	2.5	2.5	2.9	2.7	2.7	2.8	2.5	2.5	2.9	2.7	2.7	2.8	2.5	2.5	2.9	2.7	2.7
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0026	0.0024	0.0030	0.0026	0.0003	0.0003	0.0026	0.0024	0.0030	0.0026	0.0003	0.0003	0.0026	0.0024	0.0030	0.0026	0.0003	0.0003	0.0026	0.0024	0.0030	0.0026	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0013	0.0013	0.0021	0.0016	0.0002	0.0002	0.0013	0.0013	0.0021	0.0016	0.0002	0.0002	0.0013	0.0013	0.0021	0.0016	0.0002	0.0002	0.0013	0.0013	0.0021	0.0016	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.069	0.068	0.119	0.091	0.013	0.013	0.069	0.068	0.119	0.091	0.013	0.013	0.069	0.068	0.119	0.091	0.013	0.013	0.069	0.068	0.119	0.091	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.018	0.018	0.020	0.019	0.008	0.008	0.018	0.018	0.020	0.019	0.008	0.008	0.018	0.018	0.020	0.019	0.008	0.008	0.018	0.018	0.020	0.019	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.003	0.003	0.002	0.003	0.005	0.005	0.003	0.003	0.002	0.003	0.005	0.005	0.003	0.003	0.002	0.003	0.005	0.005	0.003	0.003	0.002	0.003	0.005
Iron (Fe)	mg/L	-	-	1.4	0.8	0.8	0.6	0.7	1.4	1.4	0.8	0.8	0.6	0.7	1.4	1.4	0.8	0.8	0.6	0.7	1.4	1.4	0.8	0.8	0.6	0.7	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.004	0.004	0.003	0.004	0.005	0.005	0.004	0.004	0.003	0.004	0.005	0.005	0.004	0.004	0.003	0.004	0.005	0.005	0.004	0.004	0.003	0.004	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.04	0.04	0.03	0.04	0.06	0.06	0.04	0.04	0.03	0.04	0.06	0.06	0.04	0.04	0.03	0.04	0.06	0.06	0.04	0.04	0.03	0.04	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0047	0.0046	0.0080	0.0061	0.0005	0.0005	0.0047	0.0046	0.0080	0.0061	0.0005	0.0005	0.0047	0.0046	0.0080	0.0061	0.0005	0.0005	0.0047	0.0046	0.0080	0.0061	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.005	0.005	0.004	0.005	0.008	0.008	0.005	0.005	0.004	0.005	0.008	0.008	0.005	0.005	0.004	0.005	0.008	0.008	0.005	0.005	0.004	0.005	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0013	0.0013	0.0021	0.0016	0.0001	0.0001	0.0013	0.0013	0.0021	0.0016	0.0001	0.0001	0.0013	0.0013	0.0021	0.0016	0.0001	0.0001	0.0013	0.0013	0.0021	0.0016	0.0001
Silicon (Si)	mg/L	-	-	9	5	5	4	5	9	9	5	5	4	5	9	9	5	5	4	5	9	9	5	5	4	5	9
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.006	0.007	0.006	0.004	0.005	0.006	0.006	0.007	0.006	0.004	0.005	0.006	0.006	0.007	0.006	0.004	0.005	0.006	0.006	0.007	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.006	0.006	0.007	0.006	0.002	0.002	0.006	0.006	0.007	0.006	0.002	0.002	0.006	0.006	0.007	0.006	0.002	0.002	0.006	0.006	0.007	0.006	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.004	0.004	0.006	0.005	0.002	0.003	0.004	0.004	0.006	0.005	0.002	0.003	0.004	0.004	0.006	0.005	0.002	0.003	0.004	0.004	0.006	0.005	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-3 Water Quality Results From Mine Area at Clarification Pond Outlets (continued)

Sahamarirana River Outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	26	26	31	31	40	45	26	26	31	31	40	45	26	26	31	31	40	45	26	26	31	31	40
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.03	0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.03	0.03	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.4	1.4	1.3	1.3	1.5	1.6	1.4	1.4	1.3	1.3	1.5	1.6	1.4	1.4	1.3	1.3	1.5	1.6	1.4	1.4	1.3	1.3	1.5
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	2.6	1.9	1.9	2.0	2.0	2.4	2.6	1.9	1.9	2.0	2.0	2.4	2.6	1.9	1.9	2.0	2.0	2.4	2.6	1.9	1.9	2.0	2.0	2.4
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05
Magnesium (Mg)	mg/L	-	-	8	5	5	6	6	8	8	5	5	6	6	8	8	5	5	6	6	8	8	5	5	6	6	8
Potassium (K)	mg/L	-	-	0.8	0.4	0.5	0.5	0.5	0.7	0.8	0.4	0.5	0.5	0.5	0.7	0.8	0.4	0.5	0.5	0.5	0.7	0.8	0.4	0.5	0.5	0.5	0.7
Sodium (Na)	mg/L	-	-	2.8	2.4	2.4	2.3	2.3	2.5	2.8	2.4	2.4	2.3	2.3	2.5	2.8	2.4	2.4	2.3	2.3	2.5	2.8	2.4	2.4	2.3	2.3	2.5
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	1	1	1	2	2	2	1	1	1	2	2	2	1	1	1	2	2	2	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0027	0.0027	0.0021	0.0021	0.0003	0.0003	0.0027	0.0027	0.0021	0.0021	0.0003	0.0003	0.0027	0.0027	0.0021	0.0021	0.0003	0.0003	0.0027	0.0027	0.0021	0.0021	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0012	0.0013	0.0007	0.0007	0.0001	0.0002	0.0012	0.0013	0.0007	0.0007	0.0001	0.0002	0.0012	0.0013	0.0007	0.0007	0.0001	0.0002	0.0012	0.0013	0.0007	0.0007	0.0001
Barium (Ba)	mg/L	0.7	-	0.013	0.060	0.062	0.033	0.037	0.012	0.013	0.060	0.062	0.033	0.037	0.012	0.013	0.060	0.062	0.033	0.037	0.012	0.013	0.060	0.062	0.033	0.037	0.012
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.026	0.025	0.013	0.010	0.007	0.008	0.026	0.025	0.013	0.010	0.007	0.008	0.026	0.025	0.013	0.010	0.007	0.008	0.026	0.025	0.013	0.010	0.007
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.003	0.003	0.003	0.003	0.004	0.005	0.003	0.003	0.003	0.003	0.004	0.005	0.003	0.003	0.003	0.003	0.004	0.005	0.003	0.003	0.003	0.003	0.004
Iron (Fe)	mg/L	-	-	1.4	0.8	0.8	1.0	1.0	1.3	1.4	0.8	0.8	1.0	1.0	1.3	1.4	0.8	0.8	1.0	1.0	1.3	1.4	0.8	0.8	1.0	1.0	1.3
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.04	0.04	0.05	0.04	0.06	0.06	0.04	0.04	0.05	0.04	0.06	0.06	0.04	0.04	0.05	0.04	0.06	0.06	0.04	0.04	0.05	0.04	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0044	0.0045	0.0021	0.0023	0.0005	0.0005	0.0044	0.0045	0.0021	0.0023	0.0005	0.0005	0.0044	0.0045	0.0021	0.0023	0.0005	0.0005	0.0044	0.0045	0.0021	0.0023	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.005	0.005	0.006	0.005	0.007	0.008	0.005	0.005	0.006	0.005	0.007	0.008	0.005	0.005	0.006	0.005	0.007	0.008	0.005	0.005	0.006	0.005	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0012	0.0013	0.0006	0.0007	0.0001	0.0001	0.0012	0.0013	0.0006	0.0007	0.0001	0.0001	0.0012	0.0013	0.0006	0.0007	0.0001	0.0001	0.0012	0.0013	0.0006	0.0007	0.0001
Silicon (Si)	mg/L	-	-	9	5	5	6	6	8	9	5	5	6	6	8	9	5	5	6	6	8	9	5	5	6	6	8
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.006	0.005	0.005	0.004	0.005	0.006	0.006	0.005	0.005	0.004	0.005	0.006	0.006	0.005	0.005	0.004	0.005	0.006	0.006	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.006	0.006	0.005	0.005	0.002	0.002	0.006	0.006	0.005	0.005	0.002	0.002	0.006	0.006	0.005	0.005	0.002	0.002	0.006	0.006	0.005	0.005	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.004	0.004	0.003	0.003	0.002	0.003	0.004	0.004	0.003	0.003	0.002	0.003	0.004	0.004	0.003	0.003	0.002	0.003	0.004	0.004	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-3 Water Quality Results From Mine Area at Clarification Pond Outlets (continued)

Torotorofotsy River Outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	37	41	38	44	45	45	37	41	38	44	45	45	37	41	38	44	45	45	37	41	38	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.04	0.05	0.04	0.05	0.05	0.05	0.04	0.05	0.04	0.05	0.05	0.05	0.04	0.05	0.04	0.05	0.05	0.05	0.04	0.05	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.4	2.5	2.5	2.6	2.6	2.6	2.4	2.5	2.5	2.6	2.6	2.6	2.4	2.5	2.5	2.6	2.6	2.6	2.4	2.5	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	7	8	7	8	8	8	7	8	7	8	8	8	7	8	7	8	8	8	7	8	7	8
Potassium (K)	mg/L	-	-	0.8	0.8	0.6	0.7	0.7	0.7	0.8	0.8	0.6	0.7	0.7	0.7	0.8	0.8	0.6	0.7	0.7	0.7	0.8	0.8	0.6	0.7	0.7	0.7
Sodium (Na)	mg/L	-	-	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7
Sulphate (SO ₄)	mg/L	-	-	1	1	2	1	2	1	1	1	2	1	2	1	1	1	2	1	2	1	1	1	2	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0025	0.0023	0.0023	0.0003	0.0003	0.0003	0.0025	0.0023	0.0023	0.0003	0.0003	0.0003	0.0025	0.0023	0.0023	0.0003	0.0003	0.0003	0.0025	0.0023	0.0023	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0009	0.0004	0.0007	0.0002	0.0002	0.0002	0.0009	0.0004	0.0007	0.0002	0.0002	0.0002	0.0009	0.0004	0.0007	0.0002	0.0002	0.0002	0.0009	0.0004	0.0007	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.036	0.015	0.030	0.013	0.013	0.013	0.036	0.015	0.030	0.013	0.013	0.013	0.036	0.015	0.030	0.013	0.013	0.013	0.036	0.015	0.030	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.049	0.012	0.045	0.008	0.008	0.008	0.049	0.012	0.045	0.008	0.008	0.008	0.049	0.012	0.045	0.008	0.008	0.008	0.049	0.012	0.045	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.2	1.3	1.2	1.4	1.4	1.4	1.2	1.3	1.2	1.4	1.4	1.4	1.2	1.3	1.2	1.4	1.4	1.4	1.2	1.3	1.2	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.006	0.006	0.006	0.005	0.005	0.005	0.006	0.006	0.006	0.005	0.005	0.005	0.006	0.006	0.006	0.005	0.005	0.005	0.006	0.006	0.006	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0027	0.0007	0.0023	0.0005	0.0005	0.0005	0.0027	0.0007	0.0023	0.0005	0.0005	0.0005	0.0027	0.0007	0.0023	0.0005	0.0005	0.0005	0.0027	0.0007	0.0023	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0008	0.0003	0.0007	0.0001	0.0001	0.0001	0.0008	0.0003	0.0007	0.0001	0.0001	0.0001	0.0008	0.0003	0.0007	0.0001	0.0001	0.0001	0.0008	0.0003	0.0007	0.0001
Silicon (Si)	mg/L	-	-	9	9	8	8	8	9	9	9	8	8	8	9	9	9	8	8	8	9	9	9	8	8	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.006	0.006	0.006	0.004	0.005	0.005	0.006	0.006	0.006	0.004	0.005	0.005	0.006	0.006	0.006	0.004	0.005	0.005	0.006	0.006	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.006	0.006	0.006	0.002	0.002	0.002	0.006	0.006	0.006	0.002	0.002	0.002	0.006	0.006	0.006	0.002	0.002	0.002	0.006	0.006	0.006	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-3 Water Quality Results From Mine Area at Clarification Pond Outlets (continued)

Sakalava River Outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	41	37	40	44	45	45	41	37	40	44	45	45	41	37	40	44	45	45	41	37	40	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.4	2.4	2.4	2.6	2.6	2.6	2.4	2.4	2.4	2.6	2.6	2.6	2.4	2.4	2.4	2.6	2.6	2.6	2.4	2.4	2.4	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	7	8	8	8	8	8	7	8	8	8	8	8	7	8	8	8	8	8	7	8	8
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7
Sodium (Na)	mg/L	-	-	2.8	2.8	2.5	2.4	2.5	2.7	2.8	2.8	2.5	2.4	2.5	2.7	2.8	2.8	2.5	2.4	2.5	2.7	2.8	2.8	2.5	2.4	2.5	2.7
Sulphate (SO ₄)	mg/L	-	-	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0022	0.0021	0.0018	0.0003	0.0003	0.0003	0.0022	0.0021	0.0018	0.0003	0.0003	0.0003	0.0022	0.0021	0.0018	0.0003	0.0003	0.0003	0.0022	0.0021	0.0018	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0004	0.0008	0.0003	0.0002	0.0002	0.0002	0.0004	0.0008	0.0003	0.0002	0.0002	0.0002	0.0004	0.0008	0.0003	0.0002	0.0002	0.0002	0.0004	0.0008	0.0003	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.013	0.032	0.013	0.013	0.013	0.013	0.013	0.032	0.013	0.013	0.013	0.013	0.013	0.032	0.013	0.013	0.013	0.013	0.013	0.032	0.013	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.008	0.049	0.009	0.008	0.008	0.008	0.008	0.049	0.009	0.008	0.008	0.008	0.008	0.049	0.009	0.008	0.008	0.008	0.008	0.049	0.009	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0005	0.0025	0.0006	0.0005	0.0005	0.0005	0.0005	0.0025	0.0006	0.0005	0.0005	0.0005	0.0005	0.0025	0.0006	0.0005	0.0005	0.0005	0.0005	0.0025	0.0006	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0003	0.0007	0.0002	0.0001	0.0001	0.0001	0.0003	0.0007	0.0002	0.0001	0.0001	0.0001	0.0003	0.0007	0.0002	0.0001	0.0001	0.0001	0.0003	0.0007	0.0002	0.0001
Silicon (Si)	mg/L	-	-	9	9	8	8	8	9	9	9	8	8	8	9	9	9	8	8	8	9	9	9	8	8	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.006	0.006	0.005	0.004	0.005	0.005	0.006	0.006	0.005	0.004	0.005	0.005	0.006	0.006	0.005	0.004	0.005	0.005	0.006	0.006	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.006	0.005	0.005	0.002	0.002	0.002	0.006	0.005	0.005	0.002	0.002	0.002	0.006	0.005	0.005	0.002	0.002	0.002	0.006	0.005	0.005	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-3 Water Quality Results From Mine Area at Clarification Pond Outlets (continued)

Ankaja River Outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	34	34	38	35	42	45	34	34	38	35	42	45	34	34	38	35	42	45	34	34	38	35	42
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.4	1.4	1.5	1.5	1.6	1.5	1.4	1.4	1.5	1.5	1.6	1.5	1.4	1.4	1.5	1.5	1.6	1.5	1.4	1.4	1.5	1.5
Nitrite (NO2)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	3	3	4	3	4	4	3	3	4	3	4	4	3	3	4	3	4	4	3	3	4	3	4
Chloride (Cl)	mg/L	-	-	2.6	2.3	2.2	2.3	2.3	2.5	2.6	2.3	2.2	2.3	2.3	2.5	2.6	2.3	2.2	2.3	2.3	2.5	2.6	2.3	2.2	2.3	2.3	2.5
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	6	7	7	8	8	7	6	7	7	8	8	7	6	7	7	8	8	7	6	7	7	8
Potassium (K)	mg/L	-	-	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7
Sodium (Na)	mg/L	-	-	2.8	2.3	2.3	2.3	2.3	2.6	2.8	2.3	2.3	2.3	2.3	2.6	2.8	2.3	2.3	2.3	2.3	2.6	2.8	2.3	2.3	2.3	2.3	2.6
Sulphate (SO ₄)	mg/L	-	-	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0024	0.0025	0.0023	0.0026	0.0003	0.0003	0.0024	0.0025	0.0023	0.0026	0.0003	0.0003	0.0024	0.0025	0.0023	0.0026	0.0003	0.0003	0.0024	0.0025	0.0023	0.0026	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0008	0.0008	0.0003	0.0008	0.0002	0.0002	0.0008	0.0008	0.0003	0.0008	0.0002	0.0002	0.0008	0.0008	0.0003	0.0008	0.0002	0.0002	0.0008	0.0008	0.0003	0.0008	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.032	0.031	0.012	0.030	0.012	0.013	0.032	0.031	0.012	0.030	0.012	0.013	0.032	0.031	0.012	0.030	0.012	0.013	0.032	0.031	0.012	0.030	0.012
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.048	0.041	0.007	0.047	0.007	0.008	0.048	0.041	0.007	0.047	0.007	0.008	0.048	0.041	0.007	0.047	0.007	0.008	0.048	0.041	0.007	0.047	0.007
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Iron (Fe)	mg/L	-	-	1.4	1.1	1.1	1.2	1.1	1.3	1.4	1.1	1.1	1.2	1.1	1.3	1.4	1.1	1.1	1.2	1.1	1.3	1.4	1.1	1.1	1.2	1.1	1.3
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.006	0.006	0.006	0.005	0.005	0.005	0.006	0.006	0.006	0.005	0.005	0.005	0.006	0.006	0.006	0.005	0.005	0.005	0.006	0.006	0.006	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.06	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0025	0.0023	0.0004	0.0024	0.0005	0.0005	0.0025	0.0023	0.0004	0.0024	0.0005	0.0005	0.0025	0.0023	0.0004	0.0024	0.0005	0.0005	0.0025	0.0023	0.0004	0.0024	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.007	0.006	0.007	0.008	0.006	0.006	0.007	0.006	0.007	0.008	0.006	0.006	0.007	0.006	0.007	0.008	0.006	0.006	0.007	0.006	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0008	0.0007	0.0003	0.0007	0.0001	0.0001	0.0008	0.0007	0.0003	0.0007	0.0001	0.0001	0.0008	0.0007	0.0003	0.0007	0.0001	0.0001	0.0008	0.0007	0.0003	0.0007	0.0001
Silicon (Si)	mg/L	-	-	9	7	7	8	7	8	9	7	7	8	7	8	9	7	7	8	7	8	9	7	7	8	7	8
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.006	0.006	0.006	0.004	0.005	0.006	0.006	0.006	0.006	0.004	0.005	0.006	0.006	0.006	0.006	0.004	0.005	0.006	0.006	0.006	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.006	0.006	0.006	0.006	0.002	0.002	0.006	0.006	0.006	0.006	0.002	0.002	0.006	0.006	0.006	0.006	0.002	0.002	0.006	0.006	0.006	0.006	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002

- Notes
- 1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.
- 2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.
- 3

Based on the un-ionized portion of ammonia.
- 4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.
- 5

Based on long-term exposure.
- 6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.
- 7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.
- 8

Based on an alkalinity value of less than 60 mg/L.
- 9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).
- 10

Based on the dissolved form of this metal.
- 11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.
- 12

Based on a dissolved saturation of at least 80%.
- 13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.
- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-3 Water Quality Results From Mine Area at Clarification Pond Outlets (continued)

Antsahalava River Outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	31	27	31	30	44	45	31	27	31	30	44	45	31	27	31	30	44	33	23	21	23	22	32
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.03	0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.03	0.03	0.05	0.18	0.12	0.10	0.11	0.11	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.4	1.5	1.5	1.5	1.5	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.04	0.04	0.04	0.04	0.05
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.3	2.2	2.3	2.3	2.6	2.6	2.3	2.2	2.3	2.3	2.6	2.6	2.3	2.2	2.3	2.3	2.6	3.2	2.7	2.6	2.7	2.6	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05
Magnesium (Mg)	mg/L	-	-	8	6	5	6	6	8	8	6	5	6	6	8	8	6	5	6	6	8	7	5	4	5	5	7
Potassium (K)	mg/L	-	-	0.8	0.5	0.5	0.5	0.5	0.7	0.8	0.5	0.5	0.5	0.5	0.7	0.8	0.5	0.5	0.5	0.5	0.7	0.9	0.6	0.5	0.6	0.6	0.9
Sodium (Na)	mg/L	-	-	2.8	2.9	3.1	2.9	3.0	2.7	2.8	2.9	3.1	2.9	3.0	2.7	2.8	2.9	3.1	2.9	3.0	2.7	1.3	1.9	2.2	2.0	2.1	1.3
Sulphate (SO ₄)	mg/L	-	-	1	2	3	2	2	1	1	2	3	2	2	1	1	2	3	2	2	1	2	2	3	2	3	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0028	0.0033	0.0030	0.0031	0.0003	0.0003	0.0028	0.0033	0.0030	0.0031	0.0003	0.0003	0.0028	0.0033	0.0030	0.0031	0.0003	0.0500	0.0352	0.0310	0.0350	0.0336	0.0496
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0014	0.0019	0.0015	0.0016	0.0002	0.0002	0.0014	0.0019	0.0015	0.0016	0.0002	0.0002	0.0014	0.0019	0.0015	0.0016	0.0002	0.0055	0.0049	0.0048	0.0049	0.0049	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.075	0.103	0.078	0.087	0.013	0.013	0.075	0.103	0.078	0.087	0.013	0.013	0.075	0.103	0.078	0.087	0.013	0.025	0.083	0.110	0.086	0.095	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.007	0.006	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0050	0.0035	0.0031	0.0035	0.0034	0.0050
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.024	0.025	0.023	0.023	0.008	0.008	0.024	0.025	0.023	0.023	0.008	0.008	0.024	0.025	0.023	0.023	0.008	0.006	0.023	0.024	0.022	0.022	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.005	0.003	0.003	0.003	0.003	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.004	0.003	0.004	0.003	0.005
Iron (Fe)	mg/L	-	-	1.4	1.0	0.8	0.9	0.9	1.4	1.4	1.0	0.8	0.9	0.9	1.4	1.4	1.0	0.8	0.9	0.9	1.4	1.1	0.8	0.7	0.8	0.7	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.050	0.034	0.029	0.034	0.032	0.050
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.04	0.05	0.04	0.06	0.06	0.05	0.04	0.05	0.04	0.06	0.06	0.05	0.04	0.05	0.04	0.06	0.07	0.05	0.04	0.05	0.05	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0005	0.0004	0.0003	0.0004	0.0004	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0052	0.0071	0.0054	0.0060	0.0005	0.0005	0.0052	0.0071	0.0054	0.0060	0.0005	0.0005	0.0052	0.0071	0.0054	0.0060	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.005	0.006	0.006	0.008	0.008	0.006	0.005	0.006	0.006	0.008	0.008	0.006	0.005	0.006	0.006	0.008	0.008	0.006	0.005	0.006	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0014	0.0019	0.0015	0.0016	0.0001	0.0001	0.0014	0.0019	0.0015	0.0016	0.0001	0.0001	0.0014	0.0019	0.0015	0.0016	0.0001	0.0050	0.0046	0.0046	0.0046	0.0046	0.0050
Silicon (Si)	mg/L	-	-	9	6	5	6	6	9	9	6	5	6	6	9	9	6	5	6	6	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.007	0.007	0.007	0.007	0.004	0.005	0.007	0.007	0.007	0.007	0.004	0.005	0.007	0.007	0.007	0.007	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.007	0.007	0.007	0.007	0.002	0.002	0.007	0.007	0.007	0.007	0.002	0.002	0.007	0.007	0.007	0.007	0.002	0.100	0.070	0.062	0.070	0.067	0.099
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.004	0.003	0.004	0.003	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.005	0.006	0.005	0.005	0.002	0.003	0.005	0.006	0.005	0.005	0.002	0.003	0.005	0.006	0.005	0.005	0.002	0.014	0.012	0.012	0.012	0.012	0.014

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-3 Water Quality Results From Mine Area at Clarification Pond Outlets (continued)

Sahaviara River Outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	26	27	20	24	43	45	26	27	20	24	43	45	26	27	20	24	43	33	20	20	15	18	32
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.03	0.03	0.02	0.03	0.05	0.05	0.03	0.03	0.02	0.03	0.05	0.05	0.03	0.03	0.02	0.03	0.05	0.18	0.10	0.10	0.07	0.09	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.4	1.4	1.5	1.5	1.6	1.6	1.4	1.4	1.5	1.5	1.6	1.6	1.4	1.4	1.5	1.5	1.6	1.4	1.3	1.3	1.4	1.3	1.3
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.04	0.04	0.03	0.04	0.05
Calcium (Ca)	mg/L	-	-	4	3	3	2	2	4	4	3	3	2	2	4	4	3	3	2	2	4	2	2	2	1	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.0	2.0	1.9	2.0	2.6	2.6	2.0	2.0	1.9	2.0	2.6	2.6	2.0	2.0	1.9	2.0	2.6	3.2	2.3	2.3	2.1	2.3	3.1
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	5	5	4	4	8	8	5	5	4	4	8	8	5	5	4	4	8	7	4	4	3	4	7
Potassium (K)	mg/L	-	-	0.8	0.5	0.5	0.4	0.4	0.7	0.8	0.5	0.5	0.4	0.4	0.7	0.8	0.5	0.5	0.4	0.4	0.7	0.9	0.5	0.5	0.4	0.5	0.9
Sodium (Na)	mg/L	-	-	2.8	2.5	2.5	2.9	2.7	2.7	2.8	2.5	2.5	2.9	2.7	2.7	2.8	2.5	2.5	2.9	2.7	2.7	1.3	1.7	1.7	2.3	2.0	1.2
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	2	2	2	3	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.03	0.02	0.02	0.01	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0026	0.0024	0.0030	0.0026	0.0003	0.0003	0.0026	0.0024	0.0030	0.0026	0.0003	0.0003	0.0026	0.0024	0.0030	0.0026	0.0003	0.0500	0.0301	0.0303	0.0228	0.0274	0.0486
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0013	0.0013	0.0021	0.0016	0.0002	0.0002	0.0013	0.0013	0.0021	0.0016	0.0002	0.0002	0.0013	0.0013	0.0021	0.0016	0.0002	0.0055	0.0042	0.0042	0.0042	0.0053	0.0053
Barium (Ba)	mg/L	0.7	-	0.013	0.069	0.068	0.119	0.091	0.013	0.013	0.069	0.068	0.119	0.091	0.013	0.013	0.069	0.068	0.119	0.091	0.013	0.025	0.076	0.075	0.124	0.097	0.024
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.005	0.005	0.005	0.005	0.006
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0030	0.0030	0.0023	0.0027	0.0049
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.018	0.018	0.020	0.019	0.008	0.008	0.018	0.018	0.020	0.019	0.008	0.008	0.018	0.018	0.020	0.019	0.008	0.006	0.017	0.017	0.020	0.018	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.005	0.003	0.003	0.002	0.003	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.003	0.003	0.002	0.003	0.005	0.005	0.003	0.003	0.002	0.003	0.005	0.005	0.003	0.003	0.002	0.003	0.005	0.005	0.003	0.003	0.002	0.003	0.005
Iron (Fe)	mg/L	-	-	1.4	0.8	0.8	0.6	0.7	1.4	1.4	0.8	0.8	0.6	0.7	1.4	1.4	0.8	0.8	0.6	0.7	1.4	1.1	0.7	0.7	0.5	0.6	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.004	0.004	0.003	0.004	0.005	0.005	0.004	0.004	0.003	0.004	0.005	0.005	0.004	0.004	0.003	0.004	0.005	0.050	0.029	0.029	0.021	0.026	0.049
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.04	0.04	0.03	0.04	0.06	0.06	0.04	0.04	0.03	0.04	0.06	0.06	0.04	0.04	0.03	0.04	0.06	0.07	0.04	0.04	0.03	0.04	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0005	0.0003	0.0003	0.0002	0.0003	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0047	0.0046	0.0080	0.0061	0.0005	0.0005	0.0047	0.0046	0.0080	0.0061	0.0005	0.0005	0.0047	0.0046	0.0080	0.0061	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.005	0.005	0.004	0.005	0.008	0.008	0.005	0.005	0.004	0.005	0.008	0.008	0.005	0.005	0.004	0.005	0.008	0.008	0.005	0.005	0.004	0.005	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0013	0.0013	0.0021	0.0016	0.0001	0.0001	0.0013	0.0013	0.0021	0.0016	0.0001	0.0001	0.0013	0.0013	0.0021	0.0016	0.0001	0.0050	0.0040	0.0040	0.0040	0.0041	0.0049
Silicon (Si)	mg/L	-	-	9	5	5	4	5	9	9	5	5	4	5	9	9	5	5	4	5	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.006	0.007	0.006	0.004	0.005	0.006	0.006	0.007	0.006	0.004	0.005	0.006	0.006	0.007	0.006	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.006	0.006	0.007	0.006	0.002	0.002	0.006	0.006	0.007	0.006	0.002	0.002	0.006	0.006	0.007	0.006	0.002	0.100	0.060	0.061	0.046	0.055	0.097
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.003	0.003	0.002	0.003	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.004	0.004	0.006	0.005	0.002	0.003	0.004	0.004	0.006	0.005	0.002	0.003	0.004	0.004	0.006	0.005	0.002	0.014	0.011	0.011	0.011	0.011	0.013

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-3 Water Quality Results From Mine Area at Clarification Pond Outlets (continued)

Sahamarirana River Outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	26	26	31	31	40	45	26	26	31	31	40	45	26	26	31	31	40	33	20	20	23	23	30
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.03	0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.03	0.03	0.05	0.18	0.10	0.10	0.12	0.12	0.16
Nitrate (NO ₃)	mg/L	50	-	1.6	1.4	1.4	1.3	1.3	1.5	1.6	1.4	1.4	1.3	1.3	1.5	1.6	1.4	1.4	1.3	1.3	1.5	1.4	1.2	1.2	1.1	1.1	1.3
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.05	0.04	0.04	0.04	0.04	0.05
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	1.9	1.9	2.0	2.0	2.4	2.6	1.9	1.9	2.0	2.0	2.4	2.6	1.9	1.9	2.0	2.0	2.4	3.2	2.2	2.3	2.4	2.4	2.9
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05
Magnesium (Mg)	mg/L	-	-	8	5	5	6	6	8	8	5	5	6	6	8	8	5	5	6	6	8	7	4	4	5	5	6
Potassium (K)	mg/L	-	-	0.8	0.4	0.5	0.5	0.5	0.7	0.8	0.4	0.5	0.5	0.5	0.7	0.8	0.4	0.5	0.5	0.5	0.7	0.9	0.5	0.5	0.6	0.6	0.8
Sodium (Na)	mg/L	-	-	2.8	2.4	2.4	2.3	2.3	2.5	2.8	2.4	2.4	2.3	2.3	2.5	2.8	2.4	2.4	2.3	2.3	2.5	1.3	1.6	1.6	1.3	1.3	1.2
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	1	1	1	2	2	2	1	1	1	2	2	2	1	1	2	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0027	0.0027	0.0021	0.0021	0.0003	0.0003	0.0027	0.0027	0.0021	0.0021	0.0003	0.0003	0.0027	0.0027	0.0021	0.0021	0.0003	0.0500	0.0295	0.0296	0.0352	0.0346	0.0455
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0012	0.0013	0.0007	0.0007	0.0001	0.0002	0.0012	0.0013	0.0007	0.0007	0.0001	0.0002	0.0012	0.0013	0.0007	0.0007	0.0001	0.0055	0.0041	0.0041	0.0042	0.0042	0.0050
Barium (Ba)	mg/L	0.7	-	0.013	0.060	0.062	0.033	0.037	0.012	0.013	0.060	0.062	0.033	0.037	0.012	0.013	0.060	0.062	0.033	0.037	0.012	0.025	0.066	0.069	0.041	0.045	0.023
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.005	0.005	0.005	0.005	0.006
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0030	0.0030	0.0035	0.0035	0.0045
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.026	0.025	0.013	0.010	0.007	0.008	0.026	0.025	0.013	0.010	0.007	0.008	0.026	0.025	0.013	0.010	0.007	0.006	0.025	0.024	0.012	0.009	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.005	0.003	0.003	0.004	0.003	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.003	0.003	0.003	0.003	0.004	0.005	0.003	0.003	0.003	0.003	0.004	0.005	0.003	0.003	0.003	0.003	0.004	0.005	0.003	0.003	0.004	0.003	0.005
Iron (Fe)	mg/L	-	-	1.4	0.8	0.8	1.0	1.0	1.3	1.4	0.8	0.8	1.0	1.0	1.3	1.4	0.8	0.8	1.0	1.0	1.3	1.1	0.7	0.7	0.8	0.8	1.0
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.050	0.029	0.029	0.035	0.034	0.045
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.04	0.04	0.05	0.04	0.06	0.06	0.04	0.04	0.05	0.04	0.06	0.06	0.04	0.04	0.05	0.04	0.06	0.07	0.04	0.04	0.05	0.05	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0005	0.0003	0.0003	0.0004	0.0004	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0044	0.0045	0.0021	0.0023	0.0005	0.0005	0.0044	0.0045	0.0021	0.0023	0.0005	0.0005	0.0044	0.0045	0.0021	0.0023	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.005	0.005	0.006	0.005	0.007	0.008	0.005	0.005	0.006	0.005	0.007	0.008	0.005	0.005	0.006	0.005	0.007	0.008	0.005	0.005	0.006	0.006	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0012	0.0013	0.0006	0.0007	0.0001	0.0001	0.0012	0.0013	0.0006	0.0007	0.0001	0.0001	0.0012	0.0013	0.0006	0.0007	0.0001	0.0050	0.0039	0.0039	0.0039	0.0039	0.0045
Silicon (Si)	mg/L	-	-	9	5	5	6	6	8	9	5	5	6	6	8	9	5	5	6	6	8	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.006	0.005	0.005	0.004	0.005	0.006	0.006	0.005	0.005	0.004	0.005	0.006	0.006	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.006	0.006	0.005	0.005	0.002	0.002	0.006	0.006	0.005	0.005	0.002	0.002	0.006	0.006	0.005	0.005	0.002	0.100	0.059	0.059	0.070	0.069	0.091
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.003	0.003	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.004	0.004	0.003	0.003	0.002	0.003	0.004	0.004	0.003	0.003	0.002	0.003	0.004	0.004	0.003	0.003	0.002	0.014	0.010	0.010	0.011	0.010	0.013

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-3 Water Quality Results From Mine Area at Clarification Pond Outlets (continued)

Torotorofotsy River Outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	37	41	38	44	45	45	37	41	38	44	45	45	37	41	38	44	33	33	27	29	28	32
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.04	0.05	0.04	0.05	0.05	0.05	0.04	0.05	0.04	0.05	0.05	0.05	0.04	0.05	0.04	0.05	0.18	0.18	0.14	0.15	0.15	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.4	1.4	1.4	1.3	1.4	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.4	2.5	2.5	2.6	2.6	2.6	2.4	2.5	2.5	2.6	2.6	2.6	2.4	2.5	2.5	2.6	3.2	3.2	2.9	2.9	2.9	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	7	8	7	8	8	8	7	8	7	8	8	8	7	8	7	8	7	7	6	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.8	0.6	0.7	0.7	0.7	0.8	0.8	0.6	0.7	0.7	0.7	0.8	0.8	0.6	0.7	0.7	0.7	0.9	0.9	0.7	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7	1.3	1.3	1.3	1.3	1.3	1.3
Sulphate (SO ₄)	mg/L	-	-	1	1	2	1	2	1	1	1	2	1	2	1	1	1	2	1	2	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0025	0.0023	0.0023	0.0003	0.0003	0.0003	0.0025	0.0023	0.0023	0.0003	0.0003	0.0003	0.0025	0.0023	0.0023	0.0003	0.0500	0.0500	0.0421	0.0437	0.0433	0.0496
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0009	0.0004	0.0007	0.0002	0.0002	0.0002	0.0009	0.0004	0.0007	0.0002	0.0002	0.0002	0.0009	0.0004	0.0007	0.0002	0.0055	0.0055	0.0051	0.0051	0.0051	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.036	0.015	0.030	0.013	0.013	0.013	0.036	0.015	0.030	0.013	0.013	0.013	0.036	0.015	0.030	0.013	0.025	0.025	0.045	0.038	0.040	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.007	0.007	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0050	0.0050	0.0042	0.0044	0.0043	0.0050
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.049	0.012	0.045	0.008	0.008	0.008	0.049	0.012	0.045	0.008	0.008	0.008	0.049	0.012	0.045	0.008	0.006	0.006	0.047	0.033	0.044	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.005	0.005	0.004	0.004	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.2	1.3	1.2	1.4	1.4	1.4	1.2	1.3	1.2	1.4	1.4	1.4	1.2	1.3	1.2	1.4	1.1	1.1	1.0	1.0	1.0	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.006	0.006	0.006	0.005	0.005	0.005	0.006	0.006	0.006	0.005	0.005	0.005	0.006	0.006	0.006	0.005	0.050	0.050	0.042	0.043	0.043	0.050
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0004	0.0004	0.0004	0.0005	
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0027	0.0007	0.0023	0.0005	0.0005	0.0005	0.0027	0.0007	0.0023	0.0005	0.0005	0.0005	0.0027	0.0007	0.0023	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0008	0.0003	0.0007	0.0001	0.0001	0.0001	0.0008	0.0003	0.0007	0.0001	0.0001	0.0001	0.0008	0.0003	0.0007	0.0001	0.0050	0.0050	0.0047	0.0047	0.0048	0.0050
Silicon (Si)	mg/L	-	-	9	9	8	8	8	9	9	9	8	8	8	9	9	9	8	8	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.006	0.006	0.006	0.004	0.005	0.005	0.006	0.006	0.006	0.004	0.005	0.005	0.006	0.006	0.006	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.006	0.006	0.006	0.002	0.002	0.002	0.006	0.006	0.006	0.002	0.002	0.002	0.006	0.006	0.006	0.002	0.100	0.100	0.084	0.087	0.087	0.099
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.004	0.004	0.004	0.005	
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.014	0.014	0.012	0.012	0.012	0.014

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-3 Water Quality Results From Mine Area at Clarification Pond Outlets (continued)

Sakalava River Outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	41	37	40	44	45	45	41	37	40	44	45	45	41	37	40	44	33	33	29	27	29	32
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.18	0.18	0.15	0.14	0.15	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6	1.4	1.4	1.3	1.4	1.3	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.04	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.4	2.4	2.4	2.6	2.6	2.6	2.4	2.4	2.4	2.6	2.6	2.6	2.4	2.4	2.4	2.6	3.2	3.2	2.9	2.9	2.9	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	7	8	8	8	8	8	7	8	8	8	8	8	7	8	8	7	7	6	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7	0.9	0.9	0.8	0.7	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.8	2.5	2.4	2.5	2.7	2.8	2.8	2.5	2.4	2.5	2.7	2.8	2.8	2.5	2.4	2.5	2.7	1.3	1.3	1.2	1.3	1.2	1.3
Sulphate (SO ₄)	mg/L	-	-	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0022	0.0021	0.0018	0.0003	0.0003	0.0003	0.0022	0.0021	0.0018	0.0003	0.0003	0.0003	0.0022	0.0021	0.0018	0.0003	0.0500	0.0500	0.0438	0.0420	0.0445	0.0493
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0004	0.0008	0.0003	0.0002	0.0002	0.0002	0.0004	0.0008	0.0003	0.0002	0.0002	0.0002	0.0004	0.0008	0.0003	0.0002	0.0055	0.0055	0.0050	0.0050	0.0050	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.013	0.032	0.013	0.013	0.013	0.013	0.013	0.032	0.013	0.013	0.013	0.013	0.013	0.032	0.013	0.013	0.025	0.025	0.033	0.041	0.030	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.007	0.007	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0050	0.0050	0.0044	0.0042	0.0044	0.0049
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.008	0.049	0.009	0.008	0.008	0.008	0.008	0.049	0.009	0.008	0.008	0.008	0.008	0.049	0.009	0.008	0.006	0.006	0.029	0.048	0.019	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.005	0.005	0.004	0.004	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4	1.1	1.1	1.0	1.0	1.0	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.050	0.050	0.044	0.042	0.044	0.049
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0004	0.0004	0.0004	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0005	0.0025	0.0006	0.0005	0.0005	0.0005	0.0005	0.0025	0.0006	0.0005	0.0005	0.0005	0.0005	0.0025	0.0006	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0003	0.0007	0.0002	0.0001	0.0001	0.0001	0.0003	0.0007	0.0002	0.0001	0.0001	0.0001	0.0003	0.0007	0.0002	0.0001	0.0050	0.0050	0.0046	0.0047	0.0046	0.0049
Silicon (Si)	mg/L	-	-	9	9	8	8	8	9	9	9	8	8	8	9	9	9	8	8	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.006	0.006	0.005	0.004	0.005	0.005	0.006	0.006	0.005	0.004	0.005	0.005	0.006	0.006	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.006	0.005	0.005	0.002	0.002	0.002	0.006	0.005	0.005	0.002	0.002	0.002	0.006	0.005	0.005	0.002	0.100	0.100	0.088	0.084	0.089	0.099
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.004	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.014	0.014	0.012	0.012	0.012	0.014

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-3 Water Quality Results From Mine Area at Clarification Pond Outlets (continued)

Ankaja River Outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-Closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	34	34	38	35	42	45	34	34	38	35	42	45	34	34	38	35	42	33	26	26	26	26	31
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.18	0.13	0.13	0.13	0.13	0.16
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.4	1.4	1.5	1.5	1.6	1.5	1.4	1.4	1.5	1.5	1.6	1.5	1.4	1.4	1.5	1.5	1.4	1.3	1.3	1.3	1.3	1.3
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.04	0.04	0.04	0.04	0.05
Calcium (Ca)	mg/L	-	-	4	3	3	4	3	4	4	3	3	4	3	4	4	3	3	4	3	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.3	2.2	2.3	2.3	2.5	2.6	2.3	2.2	2.3	2.3	2.5	2.6	2.3	2.2	2.3	2.3	2.5	3.2	2.7	2.7	2.7	2.7	3.0
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	6	7	7	8	8	7	6	7	7	8	8	7	6	7	7	8	7	6	5	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7	0.9	0.7	0.7	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	2.8	2.3	2.3	2.3	2.3	2.6	2.8	2.3	2.3	2.3	2.3	2.6	2.8	2.3	2.3	2.3	2.3	2.6	1.3	1.2	1.2	1.2	1.2	1.2
Sulphate (SO ₄)	mg/L	-	-	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	2	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0024	0.0025	0.0023	0.0026	0.0003	0.0003	0.0024	0.0025	0.0023	0.0026	0.0003	0.0003	0.0024	0.0025	0.0023	0.0026	0.0003	0.0500	0.0394	0.0391	0.0402	0.0399	0.0468
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0008	0.0008	0.0003	0.0008	0.0002	0.0002	0.0008	0.0008	0.0003	0.0008	0.0002	0.0002	0.0008	0.0008	0.0003	0.0008	0.0002	0.0055	0.0047	0.0047	0.0047	0.0048	0.0051
Barium (Ba)	mg/L	0.7	-	0.013	0.032	0.031	0.012	0.030	0.012	0.013	0.032	0.031	0.012	0.030	0.012	0.013	0.032	0.031	0.012	0.030	0.012	0.025	0.041	0.040	0.037	0.039	0.023
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.006	0.006	0.006	0.006	0.006
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0050	0.0039	0.0039	0.0040	0.0040	0.0047
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.048	0.041	0.007	0.047	0.007	0.008	0.048	0.041	0.007	0.047	0.007	0.008	0.048	0.041	0.007	0.047	0.007	0.006	0.047	0.040	0.040	0.046	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.005	0.004	0.004	0.004	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.1	1.1	1.2	1.1	1.3	1.4	1.1	1.1	1.2	1.1	1.3	1.4	1.1	1.1	1.2	1.1	1.3	1.1	0.9	0.9	0.9	0.9	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.006	0.006	0.006	0.005	0.005	0.005	0.006	0.006	0.006	0.005	0.005	0.005	0.006	0.006	0.006	0.005	0.050	0.039	0.039	0.040	0.039	0.047
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.06	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.06	0.07	0.06	0.06	0.06	0.06	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0025	0.0023	0.0004	0.0024	0.0005	0.0005	0.0025	0.0023	0.0004	0.0024	0.0005	0.0005	0.0025	0.0023	0.0005	0.0024	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.007	0.006	0.007	0.008	0.006	0.006	0.007	0.006	0.007	0.008	0.006	0.006	0.007	0.006	0.007	0.008	0.006	0.006	0.007	0.007	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0008	0.0007	0.0003	0.0007	0.0001	0.0001	0.0008	0.0007	0.0003	0.0007	0.0001	0.0001	0.0008	0.0007	0.0003	0.0007	0.0001	0.0050	0.0044	0.0043	0.0044	0.0044	0.0047
Silicon (Si)	mg/L	-	-	9	7	7	8	7	8	9	7	7	8	7	8	9	7	7	8	7	8	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.006	0.006	0.006	0.004	0.005	0.006	0.006	0.006	0.006	0.004	0.005	0.006	0.006	0.006	0.006	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.006	0.006	0.006	0.006	0.002	0.002	0.006	0.006	0.006	0.006	0.002	0.002	0.006	0.006	0.006	0.006	0.002	0.100	0.079	0.078	0.080	0.080	0.094
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.004	0.004	0.004	0.004	0.005	
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.014	0.011	0.011	0.012	0.012	0.013

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-4 Water Quality Results From Mine Area 500 m Downstream of Clarification Pond Outlets

Antsahalava River 500 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	24	22	24	23	32	33	24	22	24	23	32	33	24	22	24	23	32	45	32	29	32	31	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.12	0.11	0.12	0.11	0.17	0.18	0.12	0.11	0.12	0.11	0.17	0.18	0.12	0.11	0.12	0.11	0.17	0.05	0.04	0.03	0.04	0.03	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.5	1.5	1.5	1.4	1.4	1.4	1.5	1.5	1.5	1.4	1.6	1.6	1.7	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	3.2	2.7	2.6	2.7	2.7	3.2	3.2	2.7	2.6	2.7	2.7	3.2	3.2	2.7	2.6	2.7	2.7	3.2	2.6	2.3	2.3	2.3	2.3	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05
Magnesium (Mg)	mg/L	-	-	7	5	5	5	5	7	7	5	5	5	5	7	7	5	5	5	5	7	8	6	5	6	6	8
Potassium (K)	mg/L	-	-	0.9	0.6	0.6	0.6	0.6	0.9	0.9	0.6	0.6	0.6	0.6	0.9	0.9	0.6	0.6	0.6	0.6	0.9	0.8	0.6	0.5	0.6	0.5	0.8
Sodium (Na)	mg/L	-	-	1.3	1.9	2.2	1.9	2.0	1.3	1.3	1.9	2.2	1.9	2.0	1.3	1.3	1.9	2.2	1.9	2.0	1.3	2.8	2.9	3.0	2.9	2.9	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	3	2	3	2	2	2	3	2	3	2	2	2	3	2	2	2	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0365	0.0325	0.0361	0.0341	0.0496	0.0500	0.0365	0.0325	0.0361	0.0343	0.0496	0.0500	0.0365	0.0326	0.0362	0.0347	0.0496	0.0003	0.0026	0.0030	0.0028	0.0029	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0049	0.0049	0.0049	0.0049	0.0054	0.0055	0.0049	0.0049	0.0049	0.0049	0.0054	0.0055	0.0049	0.0049	0.0049	0.0049	0.0054	0.0002	0.0013	0.0017	0.0014	0.0015	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.078	0.103	0.081	0.092	0.025	0.025	0.078	0.103	0.081	0.092	0.025	0.025	0.078	0.103	0.081	0.090	0.025	0.013	0.069	0.095	0.072	0.080	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.005	0.005	0.005	0.005	0.005	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0037	0.0032	0.0036	0.0034	0.0050	0.0050	0.0037	0.0033	0.0036	0.0034	0.0050	0.0050	0.0037	0.0033	0.0036	0.0035	0.0050	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.021	0.022	0.021	0.022	0.006	0.006	0.021	0.022	0.021	0.022	0.006	0.006	0.021	0.022	0.021	0.021	0.006	0.008	0.022	0.023	0.022	0.022	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.004	0.003	0.004	0.003	0.005	0.005	0.004	0.003	0.004	0.003	0.005	0.005	0.004	0.003	0.004	0.003	0.005	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.003	0.004	0.003	0.005	0.005	0.004	0.003	0.004	0.003	0.005	0.005	0.004	0.003	0.004	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005
Iron (Fe)	mg/L	-	-	1.1	0.8	0.7	0.8	0.8	1.1	1.1	0.8	0.7	0.8	0.8	1.1	1.1	0.8	0.7	0.8	0.8	1.1	1.4	1.0	0.9	1.0	1.0	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.035	0.031	0.035	0.033	0.050	0.050	0.035	0.031	0.035	0.033	0.050	0.050	0.035	0.031	0.035	0.033	0.050	0.005	0.005	0.004	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.05	0.05	0.05	0.05	0.07	0.07	0.05	0.05	0.05	0.05	0.07	0.07	0.05	0.05	0.05	0.05	0.07	0.06	0.05	0.04	0.05	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0004	0.0003	0.0004	0.0004	0.0005	0.0005	0.0004	0.0003	0.0004	0.0004	0.0005	0.0005	0.0004	0.0003	0.0004	0.0004	0.0005	0.0002	0.0002	0.0001	0.0002	0.0001	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0048	0.0065	0.0050	0.0055	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0046	0.0047	0.0047	0.0046	0.0050	0.0050	0.0046	0.0047	0.0047	0.0047	0.0050	0.0050	0.0046	0.0047	0.0047	0.0047	0.0050	0.0001	0.0013	0.0017	0.0013	0.0015	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	6	6	6	6	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.006	0.007	0.007	0.007	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.073	0.065	0.072	0.068	0.099	0.100	0.073	0.065	0.072	0.069	0.099	0.100	0.073	0.065	0.072	0.069	0.099	0.002	0.006	0.007	0.006	0.007	0.002
Vanadium (V)	mg/L	-	-	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.012	0.012	0.012	0.012	0.014	0.014	0.012	0.012	0.012	0.012	0.014	0.014	0.012	0.012	0.012	0.012	0.014	0.003	0.005	0.006	0.005	0.005	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-4 Water Quality Results From Mine Area 500 m Downstream Clarification Pond Outlets (continued)

Sahaviara River 500 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	23	23	19	20	32	33	23	23	19	21	32	33	23	23	19	21	32	45	31	31	26	29	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.12	0.12	0.09	0.10	0.17	0.18	0.12	0.12	0.09	0.10	0.17	0.18	0.12	0.12	0.09	0.10	0.17	0.05	0.03	0.03	0.03	0.03	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.3	1.3	1.4	1.4	1.4	1.4	1.3	1.3	1.4	1.4	1.4	1.4	1.3	1.3	1.4	1.4	1.4	1.6	1.5	1.5	1.5	1.5	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	3.2	2.5	2.5	2.3	2.4	3.1	3.2	2.5	2.5	2.3	2.4	3.1	3.2	2.5	2.5	2.3	2.4	3.1	2.6	2.1	2.1	2.1	2.1	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	5	5	4	4	7	7	5	5	4	4	7	7	5	5	4	4	7	8	6	6	5	5	8
Potassium (K)	mg/L	-	-	0.9	0.6	0.6	0.5	0.5	0.9	0.9	0.6	0.6	0.5	0.5	0.9	0.9	0.6	0.6	0.5	0.5	0.9	0.8	0.5	0.5	0.4	0.5	0.7
Sodium (Na)	mg/L	-	-	1.3	1.6	1.6	2.1	1.9	1.3	1.3	1.6	1.6	2.1	1.9	1.3	1.3	1.6	1.6	2.1	1.9	1.3	2.8	2.6	2.6	2.8	2.7	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2	2	1	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0347	0.0344	0.0283	0.0308	0.0489	0.0500	0.0348	0.0344	0.0284	0.0308	0.0489	0.0500	0.0349	0.0345	0.0285	0.0309	0.0489	0.0003	0.0021	0.0019	0.0024	0.0020	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0045	0.0045	0.0044	0.0044	0.0053	0.0055	0.0045	0.0045	0.0044	0.0044	0.0053	0.0055	0.0045	0.0045	0.0044	0.0044	0.0053	0.0002	0.0010	0.0010	0.0016	0.0013	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.064	0.065	0.104	0.086	0.024	0.025	0.064	0.065	0.104	0.086	0.024	0.025	0.063	0.064	0.103	0.086	0.024	0.013	0.055	0.055	0.093	0.072	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.005	0.005	0.005	0.005	0.007	0.007	0.005	0.005	0.005	0.005	0.007	0.007	0.006	0.005	0.005	0.005	0.007	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0035	0.0034	0.0028	0.0031	0.0049	0.0050	0.0035	0.0034	0.0028	0.0031	0.0049	0.0050	0.0035	0.0035	0.0028	0.0031	0.0049	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.015	0.015	0.017	0.016	0.006	0.006	0.015	0.015	0.017	0.016	0.006	0.006	0.015	0.015	0.017	0.016	0.006	0.008	0.016	0.016	0.017	0.016	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005
Iron (Fe)	mg/L	-	-	1.1	0.8	0.8	0.6	0.7	1.1	1.1	0.8	0.8	0.6	0.7	1.1	1.1	0.8	0.8	0.6	0.7	1.1	1.4	1.0	1.0	0.8	0.9	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.034	0.034	0.027	0.030	0.049	0.050	0.034	0.034	0.027	0.030	0.049	0.050	0.034	0.034	0.027	0.030	0.049	0.005	0.004	0.004	0.004	0.004	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.05	0.05	0.04	0.04	0.07	0.07	0.05	0.05	0.04	0.04	0.07	0.07	0.05	0.05	0.04	0.04	0.07	0.06	0.05	0.05	0.04	0.04	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0004	0.0004	0.0003	0.0003	0.0005	0.0005	0.0004	0.0004	0.0003	0.0003	0.0005	0.0005	0.0004	0.0004	0.0003	0.0003	0.0005	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0037	0.0036	0.0062	0.0048	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.005	0.005	0.008	0.008	0.006	0.006	0.005	0.005	0.008	0.008	0.006	0.006	0.005	0.005	0.008	0.008	0.006	0.006	0.005	0.005	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0042	0.0042	0.0042	0.0042	0.0049	0.0050	0.0042	0.0042	0.0042	0.0042	0.0049	0.0050	0.0042	0.0042	0.0042	0.0042	0.0049	0.0001	0.0010	0.0010	0.0016	0.0012	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	6	6	5	6	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.006	0.005	0.006	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.069	0.069	0.057	0.062	0.098	0.100	0.070	0.069	0.057	0.062	0.098	0.100	0.070	0.069	0.057	0.062	0.098	0.002	0.005	0.005	0.006	0.005	0.002
Vanadium (V)	mg/L	-	-	0.005	0.004	0.004	0.003	0.003	0.005	0.005	0.004	0.004	0.003	0.003	0.005	0.005	0.004	0.004	0.003	0.003	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.011	0.011	0.011	0.011	0.013	0.014	0.011	0.011	0.011	0.011	0.013	0.014	0.011	0.011	0.011	0.011	0.013	0.003	0.004	0.004	0.005	0.005	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-4 Water Quality Results From Mine Area 500 m Downstream Clarification Pond Outlets (continued)

Sahamarirana River 500 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	21	21	24	23	30	33	21	21	24	23	30	33	21	21	24	23	30	45	28	28	33	32	41
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.11	0.10	0.12	0.12	0.16	0.18	0.11	0.10	0.12	0.12	0.16	0.18	0.11	0.10	0.12	0.12	0.16	0.05	0.03	0.03	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.2	1.3	1.2	1.1	1.3	1.4	1.2	1.3	1.2	1.1	1.3	1.4	1.2	1.3	1.2	1.1	1.3	1.6	1.4	1.4	1.3	1.3	1.5
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.02	0.02	0.02	0.02	0.02	0.01
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	3.2	2.4	2.4	2.5	2.4	3.0	3.2	2.4	2.4	2.5	2.4	3.0	3.2	2.4	2.4	2.5	2.4	3.0	2.6	2.0	2.0	2.1	2.1	2.4
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05
Magnesium (Mg)	mg/L	-	-	7	5	5	5	5	6	7	5	5	5	5	6	7	5	5	5	5	6	8	5	5	6	6	8
Potassium (K)	mg/L	-	-	0.9	0.6	0.6	0.7	0.6	0.8	0.9	0.6	0.6	0.7	0.6	0.8	0.9	0.6	0.6	0.7	0.6	0.8	0.8	0.5	0.5	0.6	0.6	0.7
Sodium (Na)	mg/L	-	-	1.3	1.6	1.6	1.3	1.3	1.2	1.3	1.6	1.6	1.3	1.3	1.2	1.3	1.6	1.6	1.3	1.3	1.2	2.8	2.4	2.5	2.3	2.3	2.5
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2	2	1	1	2	2	2	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0318	0.0317	0.0366	0.0352	0.0459	0.0500	0.0319	0.0317	0.0367	0.0350	0.0459	0.0500	0.0319	0.0318	0.0367	0.0348	0.0459	0.0003	0.0024	0.0024	0.0019	0.0019	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0042	0.0043	0.0043	0.0042	0.0050	0.0055	0.0042	0.0043	0.0043	0.0042	0.0050	0.0055	0.0042	0.0043	0.0043	0.0042	0.0050	0.0002	0.0011	0.0011	0.0006	0.0007	0.0001
Barium (Ba)	mg/L	0.7	-	0.025	0.061	0.064	0.039	0.044	0.023	0.025	0.061	0.064	0.039	0.044	0.023	0.025	0.061	0.064	0.039	0.044	0.023	0.013	0.054	0.057	0.031	0.034	0.012
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.005	0.005	0.005	0.005	0.006	0.007	0.005	0.005	0.005	0.005	0.006	0.007	0.005	0.005	0.005	0.005	0.006	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0032	0.0032	0.0037	0.0035	0.0046	0.0050	0.0032	0.0032	0.0037	0.0035	0.0046	0.0050	0.0032	0.0032	0.0037	0.0035	0.0046	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.023	0.023	0.012	0.009	0.006	0.006	0.023	0.023	0.012	0.009	0.006	0.006	0.023	0.022	0.012	0.009	0.006	0.008	0.024	0.023	0.013	0.010	0.007
Cobalt (Co)	mg/L	-	-	0.005	0.003	0.003	0.004	0.004	0.005	0.005	0.003	0.003	0.004	0.003	0.005	0.005	0.003	0.003	0.004	0.003	0.005	0.002	0.001	0.001	0.001	0.001	0.001
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.003	0.003	0.004	0.004	0.005	0.005	0.003	0.003	0.004	0.004	0.005	0.005	0.003	0.003	0.004	0.003	0.005	0.005	0.003	0.003	0.004	0.003	0.004
Iron (Fe)	mg/L	-	-	1.1	0.7	0.7	0.8	0.8	1.1	1.1	0.7	0.7	0.8	0.8	1.1	1.1	0.7	0.7	0.8	0.8	1.1	1.4	0.9	0.9	1.0	1.0	1.3
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.031	0.031	0.036	0.035	0.046	0.050	0.031	0.031	0.036	0.035	0.046	0.050	0.031	0.031	0.036	0.034	0.046	0.005	0.004	0.004	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.05	0.05	0.05	0.05	0.07	0.07	0.05	0.05	0.05	0.05	0.07	0.07	0.05	0.05	0.05	0.05	0.07	0.06	0.04	0.04	0.05	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0003	0.0003	0.0004	0.0004	0.0005	0.0005	0.0003	0.0003	0.0004	0.0004	0.0005	0.0005	0.0003	0.0003	0.0004	0.0004	0.0005	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0039	0.0041	0.0020	0.0021	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.005	0.005	0.006	0.006	0.007	0.008	0.005	0.005	0.006	0.006	0.007	0.008	0.005	0.005	0.006	0.006	0.007	0.008	0.005	0.005	0.006	0.006	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0040	0.0040	0.0040	0.0039	0.0046	0.0050	0.0040	0.0040	0.0040	0.0039	0.0046	0.0050	0.0040	0.0040	0.0040	0.0039	0.0046	0.0001	0.0011	0.0011	0.0006	0.0006	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	6	6	7	7	8
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.006	0.006	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.064	0.063	0.073	0.070	0.092	0.100	0.064	0.063	0.073	0.070	0.092	0.100	0.064	0.064	0.073	0.070	0.092	0.002	0.006	0.006	0.005	0.005	0.002
Vanadium (V)	mg/L	-	-	0.005	0.003	0.003	0.004	0.004	0.005	0.005	0.003	0.003	0.004	0.004	0.005	0.005	0.003	0.003	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.011	0.011	0.011	0.011	0.013	0.014	0.011	0.011	0.011	0.011	0.013	0.014	0.011	0.011	0.011	0.010	0.013	0.003	0.004	0.004	0.003	0.003	0.002

- Notes
- ¹ World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.
 - ² Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.
 - ³ Based on the un-ionized portion of ammonia.
 - ⁴ Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.
 - ⁵ Based on long-term exposure.
 - ⁶ Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.
 - ⁷ Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.
 - ⁸ Based on an alkalinity value of less than 60 mg/L.
 - ⁹ Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).
 - ¹⁰ Based on the dissolved form of this metal.
 - ¹¹ Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.
 - ¹² Based on a dissolved saturation of at least 80%.
 - ¹³ Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.
 - No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-4 Water Quality Results From Mine Area 500 m Downstream Clarification Pond Outlets (continued)

Torotorofotsy River 500 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	33	28	28	29	32	33	33	28	29	29	32	33	33	28	30	29	32	45	45	37	41	38	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.18	0.14	0.15	0.15	0.17	0.18	0.18	0.14	0.15	0.15	0.17	0.18	0.18	0.14	0.15	0.15	0.17	0.05	0.05	0.04	0.05	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.4	1.4	1.4	1.4	1.4	1.3	1.4	1.4	1.6	1.6	1.6	1.5	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.2	2.9	2.9	3.0	3.2	3.2	3.2	2.9	3.0	3.0	3.2	3.2	3.2	2.9	3.0	3.0	3.2	2.6	2.6	2.4	2.5	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	7	7	6	6	6	7	7	7	6	6	6	7	7	7	6	6	6	7	8	8	7	8	7	8
Potassium (K)	mg/L	-	-	0.9	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.9	0.8	0.8	0.6	0.7	0.8	
Sodium (Na)	mg/L	-	-	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.2	1.3	1.3	2.8	2.8	2.5	2.5	2.5	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	2	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0500	0.0426	0.0433	0.0438	0.0496	0.0500	0.0500	0.0426	0.0441	0.0438	0.0496	0.0500	0.0500	0.0426	0.0453	0.0438	0.0496	0.0003	0.0003	0.0024	0.0022	0.0022	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0055	0.0051	0.0051	0.0051	0.0054	0.0055	0.0055	0.0051	0.0051	0.0051	0.0054	0.0055	0.0055	0.0051	0.0051	0.0051	0.0054	0.0002	0.0002	0.0008	0.0004	0.0007	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.025	0.044	0.040	0.039	0.025	0.025	0.025	0.044	0.037	0.039	0.025	0.025	0.025	0.044	0.032	0.039	0.025	0.013	0.013	0.034	0.015	0.029	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0050	0.0043	0.0043	0.0044	0.0050	0.0050	0.0050	0.0043	0.0044	0.0044	0.0050	0.0050	0.0050	0.0043	0.0045	0.0044	0.0050	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.006	0.044	0.038	0.041	0.006	0.006	0.006	0.044	0.031	0.041	0.006	0.006	0.006	0.044	0.021	0.041	0.006	0.008	0.008	0.046	0.012	0.042	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.1	1.0	1.0	1.0	1.1	1.1	1.1	1.0	1.0	1.0	1.1	1.1	1.1	1.0	1.0	1.0	1.1	1.4	1.4	1.2	1.3	1.2	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.050	0.042	0.043	0.043	0.050	0.050	0.050	0.042	0.044	0.043	0.050	0.050	0.050	0.042	0.045	0.043	0.050	0.005	0.005	0.006	0.006	0.006	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.07	0.06	0.06	0.06	0.07	0.07	0.07	0.06	0.06	0.06	0.07	0.07	0.07	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0004	0.0004	0.0004	0.0005	0.0005	0.0005	0.0004	0.0004	0.0004	0.0005	0.0005	0.0005	0.0004	0.0005	0.0004	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0005	0.0026	0.0007	0.0022	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0050	0.0047	0.0047	0.0048	0.0050	0.0050	0.0050	0.0047	0.0047	0.0048	0.0050	0.0050	0.0050	0.0047	0.0047	0.0048	0.0050	0.0001	0.0001	0.0008	0.0003	0.0006	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	9	8	8	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.006	0.006	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.100	0.085	0.087	0.088	0.099	0.100	0.100	0.085	0.088	0.088	0.099	0.100	0.100	0.085	0.091	0.088	0.099	0.002	0.002	0.006	0.006	0.006	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.014	0.012	0.012	0.013	0.014	0.014	0.014	0.012	0.012	0.013	0.014	0.014	0.014	0.012	0.013	0.013	0.014	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-4 Water Quality Results From Mine Area 500 m Downstream Clarification Pond Outlets (continued)

Sakalava River 500 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	33	28	28	28	32	33	33	29	28	29	32	33	33	30	28	30	32	45	45	41	37	41	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.18	0.15	0.14	0.15	0.17	0.18	0.18	0.15	0.14	0.15	0.17	0.18	0.18	0.15	0.14	0.16	0.17	0.05	0.05	0.05	0.04	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.4	1.6	1.6	1.5	1.6	1.5	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.2	2.9	2.9	2.9	3.2	3.2	3.2	2.9	2.9	2.9	3.2	3.2	3.2	3.0	2.9	3.0	3.2	2.6	2.6	2.5	2.4	2.4	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	7	6	6	6	7	7	7	6	6	6	7	7	7	6	6	6	7	8	8	8	7	8	8
Potassium (K)	mg/L	-	-	0.9	0.9	0.8	0.7	0.8	0.9	0.9	0.9	0.8	0.7	0.8	0.9	0.9	0.9	0.8	0.7	0.8	0.9	0.8	0.8	0.7	0.6	0.7	0.7
Sodium (Na)	mg/L	-	-	1.3	1.3	1.2	1.3	1.2	1.3	1.3	1.3	1.2	1.3	1.2	1.3	1.3	1.3	1.2	1.3	1.2	1.3	2.8	2.8	2.5	2.5	2.5	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	1	1	1	2	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0500	0.0432	0.0423	0.0431	0.0493	0.0500	0.0500	0.0440	0.0423	0.0446	0.0493	0.0500	0.0500	0.0452	0.0423	0.0460	0.0493	0.0003	0.0003	0.0022	0.0020	0.0017	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0055	0.0050	0.0050	0.0050	0.0054	0.0055	0.0055	0.0050	0.0050	0.0050	0.0054	0.0055	0.0055	0.0050	0.0050	0.0050	0.0054	0.0002	0.0002	0.0003	0.0007	0.0003	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.025	0.036	0.041	0.037	0.025	0.025	0.025	0.033	0.041	0.030	0.025	0.025	0.025	0.028	0.041	0.024	0.025	0.013	0.013	0.013	0.031	0.013	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0050	0.0043	0.0042	0.0043	0.0049	0.0050	0.0050	0.0044	0.0042	0.0045	0.0049	0.0050	0.0050	0.0045	0.0042	0.0046	0.0049	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.006	0.037	0.046	0.032	0.006	0.006	0.006	0.029	0.046	0.019	0.006	0.006	0.006	0.017	0.046	0.007	0.006	0.008	0.008	0.008	0.048	0.009	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.002	0.002	0.002	0.001	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.1	1.0	1.0	1.0	1.1	1.1	1.1	1.0	1.0	1.0	1.1	1.1	1.1	1.0	1.0	1.1	1.1	1.4	1.4	1.3	1.2	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.050	0.043	0.042	0.043	0.049	0.050	0.050	0.044	0.042	0.044	0.049	0.050	0.050	0.045	0.042	0.046	0.049	0.005	0.005	0.006	0.005	0.006	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.07	0.06	0.06	0.06	0.07	0.07	0.07	0.06	0.06	0.06	0.07	0.07	0.07	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.05	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0004	0.0004	0.0004	0.0005	0.0005	0.0005	0.0004	0.0004	0.0004	0.0005	0.0005	0.0005	0.0005	0.0004	0.0005	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0005	0.0005	0.0024	0.0005	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0050	0.0047	0.0047	0.0046	0.0049	0.0050	0.0050	0.0047	0.0047	0.0046	0.0049	0.0050	0.0050	0.0046	0.0047	0.0046	0.0049	0.0001	0.0001	0.0003	0.0007	0.0002	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	9	8	8	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.006	0.006	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.100	0.086	0.085	0.086	0.099	0.100	0.100	0.088	0.085	0.089	0.099	0.100	0.100	0.090	0.085	0.092	0.099	0.002	0.002	0.006	0.005	0.005	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.014	0.012	0.012	0.012	0.014	0.014	0.014	0.012	0.012	0.012	0.014	0.014	0.014	0.012	0.012	0.012	0.014	0.003	0.003	0.002	0.003	0.002	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-4 Water Quality Results From Mine Area 500 m Downstream Clarification Pond Outlets (continued)

Ankaja River 500 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	26	26	27	26	31	33	26	26	27	26	31	33	26	26	27	26	31	45	35	35	39	36	42
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.14	0.13	0.14	0.14	0.16	0.18	0.14	0.13	0.14	0.14	0.16	0.18	0.14	0.13	0.14	0.14	0.16	0.05	0.04	0.04	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.6	1.5	1.5	1.4	1.5	1.5
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	3	3	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	2.7	2.7	2.8	2.8	3.0	3.2	2.7	2.7	2.8	2.8	3.0	3.2	2.7	2.7	2.8	2.8	3.0	2.6	2.3	2.3	2.3	2.3	2.5
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	6	6	6	6	7	7	6	6	6	6	7	7	6	6	6	6	7	8	7	7	7	7	8
Potassium (K)	mg/L	-	-	0.9	0.7	0.7	0.7	0.7	0.8	0.9	0.7	0.7	0.7	0.7	0.8	0.9	0.7	0.7	0.7	0.7	0.8	0.8	0.6	0.6	0.7	0.6	0.7
Sodium (Na)	mg/L	-	-	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.2	1.2	1.2	1.2	1.2	2.8	2.3	2.3	2.4	2.3	2.6
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2	2	1	1	2	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0402	0.0395	0.0407	0.0405	0.0470	0.0500	0.0402	0.0400	0.0410	0.0405	0.0470	0.0500	0.0402	0.0400	0.0414	0.0405	0.0470	0.0003	0.0023	0.0023	0.0021	0.0024	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0048	0.0047	0.0048	0.0048	0.0051	0.0055	0.0048	0.0047	0.0048	0.0048	0.0051	0.0055	0.0048	0.0047	0.0048	0.0048	0.0051	0.0002	0.0008	0.0007	0.0003	0.0008	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.040	0.041	0.037	0.039	0.023	0.025	0.040	0.038	0.036	0.039	0.023	0.025	0.040	0.038	0.034	0.039	0.023	0.013	0.031	0.029	0.012	0.029	0.012
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006	0.006	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0040	0.0040	0.0041	0.0041	0.0047	0.0050	0.0040	0.0040	0.0041	0.0041	0.0047	0.0050	0.0040	0.0040	0.0041	0.0041	0.0047	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.044	0.042	0.041	0.043	0.006	0.006	0.044	0.037	0.038	0.043	0.006	0.006	0.044	0.037	0.034	0.043	0.006	0.008	0.045	0.038	0.007	0.045	0.007
Cobalt (Co)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.002	0.001	0.001	0.002	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.004
Iron (Fe)	mg/L	-	-	1.1	0.9	0.9	0.9	0.9	1.1	1.1	0.9	0.9	0.9	0.9	1.1	1.1	0.9	0.9	1.0	0.9	1.1	1.4	1.1	1.1	1.2	1.1	1.3
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.040	0.039	0.040	0.040	0.047	0.050	0.040	0.040	0.041	0.040	0.047	0.050	0.040	0.040	0.041	0.040	0.047	0.005	0.005	0.005	0.006	0.006	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.06	0.05	0.05	0.06	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0024	0.0022	0.0004	0.0023	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.006	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.006	0.006	0.007	0.006	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0045	0.0044	0.0045	0.0045	0.0047	0.0050	0.0045	0.0044	0.0045	0.0045	0.0047	0.0050	0.0045	0.0044	0.0045	0.0045	0.0047	0.0001	0.0007	0.0007	0.0003	0.0007	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	7	7	8	7	8
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.006	0.006	0.005	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.080	0.079	0.081	0.081	0.094	0.100	0.080	0.080	0.082	0.081	0.094	0.100	0.080	0.080	0.083	0.081	0.094	0.002	0.006	0.006	0.005	0.006	0.002
Vanadium (V)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.012	0.011	0.012	0.012	0.013	0.014	0.012	0.011	0.012	0.012	0.013	0.014	0.012	0.011	0.012	0.012	0.013	0.003	0.003	0.003	0.002	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-4 Water Quality Results From Mine Area 500 m Downstream Clarification Pond Outlets (continued)

Antsahalava River 500 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	32	29	32	31	44	45	32	29	32	31	44	45	32	29	32	31	44	45	32	29	32	31	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.03	0.04	0.03	0.05	0.05	0.04	0.03	0.04	0.03	0.05	0.05	0.04	0.03	0.04	0.03	0.05	0.05	0.04	0.03	0.04	0.03	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	2.6	2.3	2.3	2.3	2.3	2.6	2.6	2.3	2.3	2.3	2.3	2.6	2.6	2.3	2.3	2.3	2.3	2.6	2.6	2.3	2.3	2.3	2.3	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05
Magnesium (Mg)	mg/L	-	-	8	6	5	6	6	8	8	6	5	6	6	8	8	6	5	6	6	8	8	6	5	6	6	8
Potassium (K)	mg/L	-	-	0.8	0.6	0.5	0.6	0.5	0.8	0.8	0.6	0.5	0.6	0.5	0.8	0.8	0.6	0.5	0.6	0.5	0.8	0.8	0.6	0.5	0.6	0.5	0.8
Sodium (Na)	mg/L	-	-	2.8	2.9	3.0	2.9	2.9	2.7	2.8	2.9	3.0	2.9	2.9	2.7	2.8	2.9	3.0	2.9	2.9	2.7	2.8	2.9	3.0	2.9	2.9	2.7
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0026	0.0030	0.0028	0.0029	0.0003	0.0003	0.0026	0.0030	0.0028	0.0029	0.0003	0.0003	0.0026	0.0030	0.0028	0.0029	0.0003	0.0003	0.0026	0.0030	0.0028	0.0029	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0013	0.0017	0.0014	0.0015	0.0002	0.0002	0.0013	0.0017	0.0014	0.0015	0.0002	0.0002	0.0013	0.0017	0.0014	0.0015	0.0002	0.0002	0.0013	0.0017	0.0014	0.0015	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.069	0.095	0.072	0.080	0.013	0.013	0.069	0.095	0.072	0.080	0.013	0.013	0.069	0.095	0.072	0.080	0.013	0.013	0.069	0.095	0.072	0.080	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.022	0.023	0.022	0.022	0.008	0.008	0.022	0.023	0.022	0.022	0.008	0.008	0.022	0.023	0.022	0.022	0.008	0.008	0.022	0.023	0.022	0.022	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005
Iron (Fe)	mg/L	-	-	1.4	1.0	0.9	1.0	1.0	1.4	1.4	1.0	0.9	1.0	1.0	1.4	1.4	1.0	0.9	1.0	1.0	1.4	1.4	1.0	0.9	1.0	1.0	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.04	0.05	0.05	0.06	0.06	0.05	0.04	0.05	0.05	0.06	0.06	0.05	0.04	0.05	0.05	0.06	0.06	0.05	0.04	0.05	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0001	0.0002	0.0001	0.0002	0.0002	0.0002	0.0001	0.0002	0.0001	0.0002	0.0002	0.0002	0.0001	0.0002	0.0001	0.0002	0.0002	0.0002	0.0001	0.0002	0.0001	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0048	0.0065	0.0050	0.0055	0.0005	0.0005	0.0048	0.0065	0.0050	0.0055	0.0005	0.0005	0.0048	0.0065	0.0050	0.0055	0.0005	0.0005	0.0048	0.0065	0.0050	0.0055	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0013	0.0017	0.0013	0.0015	0.0001	0.0001	0.0013	0.0017	0.0013	0.0015	0.0001	0.0001	0.0013	0.0017	0.0013	0.0015	0.0001	0.0001	0.0013	0.0017	0.0013	0.0015	0.0001
Silicon (Si)	mg/L	-	-	9	6	6	6	6	9	9	6	6	6	6	9	9	6	6	6	6	9	9	6	6	6	6	9
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.007	0.007	0.007	0.004	0.005	0.006	0.007	0.007	0.007	0.004	0.005	0.006	0.007	0.007	0.007	0.004	0.005	0.006	0.007	0.007	0.007	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.006	0.007	0.006	0.007	0.002	0.002	0.006	0.007	0.006	0.007	0.002	0.002	0.006	0.007	0.006	0.007	0.002	0.002	0.006	0.007	0.006	0.007	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.005	0.006	0.005	0.005	0.002	0.003	0.005	0.006	0.005	0.005	0.002	0.003	0.005	0.006	0.005	0.005	0.002	0.003	0.005	0.006	0.005	0.005	0.002

Notes

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World Health Organization (WH

Notes

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-4 Water Quality Results From Mine Area 500 m Downstream Clarification Pond Outlets (continued)

Sahaviara River 500 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	31	31	26	29	44	45	31	31	26	29	44	45	31	31	26	29	44	45	31	31	26	29	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.03	0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.03	0.03	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	2.6	2.1	2.1	2.1	2.1	2.6	2.6	2.1	2.1	2.1	2.1	2.6	2.6	2.1	2.1	2.1	2.1	2.6	2.6	2.1	2.1	2.1	2.1	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	6	6	5	5	8	8	6	6	5	5	8	8	6	6	5	5	8	8	6	6	5	5	8
Potassium (K)	mg/L	-	-	0.8	0.5	0.5	0.4	0.5	0.7	0.8	0.5	0.5	0.4	0.5	0.7	0.8	0.5	0.5	0.4	0.5	0.7	0.8	0.5	0.5	0.4	0.5	0.7
Sodium (Na)	mg/L	-	-	2.8	2.6	2.6	2.8	2.7	2.7	2.8	2.6	2.6	2.8	2.7	2.7	2.8	2.6	2.6	2.8	2.7	2.7	2.8	2.6	2.6	2.8	2.7	2.7
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0021	0.0019	0.0024	0.0020	0.0003	0.0003	0.0021	0.0019	0.0024	0.0020	0.0003	0.0003	0.0021	0.0019	0.0024	0.0020	0.0003	0.0003	0.0021	0.0019	0.0024	0.0020	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0010	0.0010	0.0016	0.0013	0.0002	0.0002	0.0010	0.0010	0.0016	0.0013	0.0002	0.0002	0.0010	0.0010	0.0016	0.0013	0.0002	0.0002	0.0010	0.0010	0.0016	0.0013	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.055	0.055	0.093	0.072	0.013	0.013	0.055	0.055	0.093	0.072	0.013	0.013	0.055	0.055	0.093	0.072	0.013	0.013	0.055	0.055	0.093	0.072	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.016	0.016	0.017	0.016	0.008	0.008	0.016	0.016	0.017	0.016	0.008	0.008	0.016	0.016	0.017	0.016	0.008	0.008	0.016	0.016	0.017	0.016	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005
Iron (Fe)	mg/L	-	-	1.4	1.0	1.0	0.8	0.9	1.4	1.4	1.0	1.0	0.8	0.9	1.4	1.4	1.0	1.0	0.8	0.9	1.4	1.4	1.0	1.0	0.8	0.9	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.04	0.04	0.06	0.06	0.05	0.05	0.04	0.04	0.06	0.06	0.05	0.05	0.04	0.04	0.06	0.06	0.05	0.05	0.04	0.04	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0037	0.0036	0.0062	0.0048	0.0005	0.0005	0.0037	0.0036	0.0062	0.0048	0.0005	0.0005	0.0037	0.0036	0.0062	0.0048	0.0005	0.0005	0.0037	0.0036	0.0062	0.0048	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.005	0.005	0.008	0.008	0.006	0.006	0.005	0.005	0.008	0.008	0.006	0.006	0.005	0.005	0.008	0.008	0.006	0.006	0.005	0.005	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0010	0.0010	0.0016	0.0012	0.0001	0.0001	0.0010	0.0010	0.0016	0.0012	0.0001	0.0001	0.0010	0.0010	0.0016	0.0012	0.0001	0.0001	0.0010	0.0010	0.0016	0.0012	0.0001
Silicon (Si)	mg/L	-	-	9	6	6	5	6	9	9	6	6	5	6	9	9	6	6	5	6	9	9	6	6	5	6	9
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.005	0.006	0.006	0.004	0.005	0.006	0.005	0.006	0.006	0.004	0.005	0.006	0.005	0.006	0.006	0.004	0.005	0.006	0.005	0.006	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.005	0.005	0.006	0.005	0.002	0.002	0.005	0.005	0.006	0.005	0.002	0.002	0.005	0.005	0.006	0.005	0.002	0.002	0.005	0.005	0.006	0.005	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.004	0.004	0.005	0.005	0.002	0.003	0.004	0.004	0.005	0.005	0.002	0.003	0.004	0.004	0.005	0.005	0.002	0.003	0.004	0.004	0.005	0.005	0.002

Notes

1

World Health Organization (WH

Notes

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-4 Water Quality Results From Mine Area 500 m Downstream Clarification Pond Outlets (continued)

Sahamarirana River 500 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	28	28	33	32	41	45	28	28	33	32	41	45	28	28	33	32	41	45	28	28	33	32	41
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.03	0.03	0.04	0.04	0.05	0.05	0.03	0.03	0.04	0.04	0.05	0.05	0.03	0.03	0.04	0.04	0.05	0.05	0.03	0.03	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.4	1.4	1.3	1.3	1.5	1.6	1.4	1.4	1.3	1.3	1.5	1.6	1.4	1.4	1.3	1.3	1.5	1.6	1.4	1.4	1.3	1.3	1.5
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	2.6	2.0	2.0	2.1	2.1	2.4	2.6	2.0	2.0	2.1	2.1	2.4	2.6	2.0	2.0	2.1	2.1	2.4	2.6	2.0	2.0	2.1	2.1	2.4
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05
Magnesium (Mg)	mg/L	-	-	8	5	5	6	6	8	8	5	5	6	6	8	8	5	5	6	6	8	8	5	5	6	6	8
Potassium (K)	mg/L	-	-	0.8	0.5	0.5	0.6	0.6	0.7	0.8	0.5	0.5	0.6	0.6	0.7	0.8	0.5	0.5	0.6	0.6	0.7	0.8	0.5	0.5	0.6	0.6	0.7
Sodium (Na)	mg/L	-	-	2.8	2.4	2.5	2.3	2.3	2.5	2.8	2.4	2.5	2.3	2.3	2.5	2.8	2.4	2.5	2.3	2.3	2.5	2.8	2.4	2.5	2.3	2.3	2.5
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	1	1	1	2	2	2	1	1	1	2	2	2	1	1	1	2	2	2	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0024	0.0024	0.0019	0.0019	0.0003	0.0003	0.0024	0.0024	0.0019	0.0019	0.0003	0.0003	0.0024	0.0024	0.0019	0.0019	0.0003	0.0003	0.0024	0.0024	0.0019	0.0019	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0011	0.0011	0.0006	0.0007	0.0001	0.0002	0.0011	0.0011	0.0006	0.0007	0.0001	0.0002	0.0011	0.0011	0.0006	0.0007	0.0001	0.0002	0.0011	0.0011	0.0006	0.0007	0.0001
Barium (Ba)	mg/L	0.7	-	0.013	0.054	0.057	0.031	0.034	0.012	0.013	0.054	0.057	0.031	0.034	0.012	0.013	0.054	0.057	0.031	0.034	0.012	0.013	0.054	0.057	0.031	0.034	0.012
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.024	0.023	0.013	0.010	0.007	0.008	0.024	0.023	0.013	0.010	0.007	0.008	0.024	0.023	0.013	0.010	0.007	0.008	0.024	0.023	0.013	0.010	0.007
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.003	0.003	0.004	0.003	0.004	0.005	0.003	0.003	0.004	0.003	0.004	0.005	0.003	0.003	0.004	0.003	0.004	0.005	0.003	0.003	0.004	0.003	0.004
Iron (Fe)	mg/L	-	-	1.4	0.9	0.9	1.0	1.0	1.3	1.4	0.9	0.9	1.0	1.0	1.3	1.4	0.9	0.9	1.0	1.0	1.3	1.4	0.9	0.9	1.0	1.0	1.3
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.04	0.04	0.05	0.05	0.06	0.06	0.04	0.04	0.05	0.05	0.06	0.06	0.04	0.04	0.05	0.05	0.06	0.06	0.04	0.04	0.05	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0039	0.0041	0.0020	0.0021	0.0005	0.0005	0.0039	0.0041	0.0020	0.0021	0.0005	0.0005	0.0039	0.0041	0.0020	0.0021	0.0005	0.0005	0.0039	0.0041	0.0020	0.0021	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.005	0.005	0.006	0.006	0.007	0.008	0.005	0.005	0.006	0.006	0.007	0.008	0.005	0.005	0.006	0.006	0.007	0.008	0.005	0.005	0.006	0.006	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0011	0.0011	0.0006	0.0006	0.0001	0.0001	0.0011	0.0011	0.0006	0.0006	0.0001	0.0001	0.0011	0.0011	0.0006	0.0006	0.0001	0.0001	0.0011	0.0011	0.0006	0.0006	0.0001
Silicon (Si)	mg/L	-	-	9	6	6	7	7	8	9	6	6	7	7	8	9	6	6	7	7	8	9	6	6	7	7	8
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.006	0.005	0.005	0.004	0.005	0.006	0.006	0.005	0.005	0.004	0.005	0.006	0.006	0.005	0.005	0.004	0.005	0.006	0.006	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.006	0.006	0.005	0.005	0.002	0.002	0.006	0.006	0.005	0.005	0.002	0.002	0.006	0.006	0.005	0.005	0.002	0.002	0.006	0.006	0.005	0.005	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.004	0.004	0.003	0.003	0.002	0.003	0.004	0.004	0.003	0.003	0.002	0.003	0.004	0.004	0.003	0.003	0.002	0.003	0.004	0.004	0.003	0.003	0.002

Notes

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World Health Organization (WH

Notes

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-4 Water Quality Results From Mine Area 500 m Downstream Clarification Pond Outlets (continued)

Torotorofotsy River 500 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	37	41	38	44	45	45	37	41	38	44	45	45	37	41	38	44	45	45	37	41	38	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.04	0.05	0.04	0.05	0.05	0.05	0.04	0.05	0.04	0.05	0.05	0.05	0.04	0.05	0.04	0.05	0.05	0.05	0.04	0.05	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.4	2.5	2.5	2.6	2.6	2.6	2.4	2.5	2.5	2.6	2.6	2.6	2.4	2.5	2.5	2.6	2.6	2.6	2.4	2.5	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	7	8	7	8	8	8	7	8	7	8	8	8	7	8	7	8	8	8	7	8	7	8
Potassium (K)	mg/L	-	-	0.8	0.8	0.6	0.7	0.7	0.8	0.8	0.8	0.6	0.7	0.7	0.8	0.8	0.8	0.6	0.7	0.7	0.8	0.8	0.8	0.6	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7
Sulphate (SO ₄)	mg/L	-	-	1	1	2	1	2	1	1	1	2	1	2	1	1	1	2	1	2	1	1	1	2	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0024	0.0022	0.0022	0.0003	0.0003	0.0003	0.0024	0.0022	0.0022	0.0003	0.0003	0.0003	0.0024	0.0022	0.0022	0.0003	0.0003	0.0003	0.0024	0.0022	0.0022	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0008	0.0004	0.0007	0.0002	0.0002	0.0002	0.0008	0.0004	0.0007	0.0002	0.0002	0.0002	0.0008	0.0004	0.0007	0.0002	0.0002	0.0002	0.0008	0.0004	0.0007	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.034	0.015	0.029	0.013	0.013	0.013	0.034	0.015	0.029	0.013	0.013	0.013	0.034	0.015	0.029	0.013	0.013	0.013	0.034	0.015	0.029	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.046	0.012	0.042	0.008	0.008	0.008	0.046	0.012	0.042	0.008	0.008	0.008	0.046	0.012	0.042	0.008	0.008	0.008	0.046	0.012	0.042	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.2	1.3	1.2	1.4	1.4	1.4	1.2	1.3	1.2	1.4	1.4	1.4	1.2	1.3	1.2	1.4	1.4	1.4	1.2	1.3	1.2	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.006	0.006	0.006	0.005	0.005	0.005	0.006	0.006	0.006	0.005	0.005	0.005	0.006	0.006	0.006	0.005	0.005	0.005	0.006	0.006	0.006	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0026	0.0007	0.0022	0.0005	0.0005	0.0005	0.0026	0.0007	0.0022	0.0005	0.0005	0.0005	0.0026	0.0007	0.0022	0.0005	0.0005	0.0005	0.0026	0.0007	0.0022	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0008	0.0003	0.0006	0.0001	0.0001	0.0001	0.0008	0.0003	0.0006	0.0001	0.0001	0.0001	0.0008	0.0003	0.0006	0.0001	0.0001	0.0001	0.0008	0.0003	0.0006	0.0001
Silicon (Si)	mg/L	-	-	9	9	8	8	8	9	9	9	8	8	8	9	9	9	8	8	8	9	9	9	8	8	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.006	0.006	0.006	0.004	0.005	0.005	0.006	0.006	0.006	0.004	0.005	0.005	0.006	0.006	0.006	0.004	0.005	0.005	0.006	0.006	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.006	0.006	0.006	0.002	0.002	0.002	0.006	0.006	0.006	0.002	0.002	0.002	0.006	0.006	0.006	0.002	0.002	0.002	0.006	0.006	0.006	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WH

Notes

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-4 Water Quality Results From Mine Area 500 m Downstream Clarification Pond Outlets (continued)

Sakalava River 500 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	41	37	41	44	45	45	41	37	41	44	45	45	41	37	41	44	45	45	41	37	41	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.5	2.4	2.4	2.6	2.6	2.6	2.5	2.4	2.4	2.6	2.6	2.6	2.5	2.4	2.4	2.6	2.6	2.6	2.5	2.4	2.4	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	7	8	8	8	8	8	7	8	8	8	8	8	7	8	8	8	8	8	7	8	8
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7
Sodium (Na)	mg/L	-	-	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7
Sulphate (SO ₄)	mg/L	-	-	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0022	0.0020	0.0017	0.0003	0.0003	0.0003	0.0022	0.0020	0.0017	0.0003	0.0003	0.0003	0.0022	0.0020	0.0017	0.0003	0.0003	0.0003	0.0022	0.0020	0.0017	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0003	0.0007	0.0003	0.0002	0.0002	0.0002	0.0003	0.0007	0.0003	0.0002	0.0002	0.0002	0.0003	0.0007	0.0003	0.0002	0.0002	0.0002	0.0003	0.0007	0.0003	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.013	0.031	0.013	0.013	0.013	0.013	0.013	0.031	0.013	0.013	0.013	0.013	0.013	0.031	0.013	0.013	0.013	0.013	0.013	0.031	0.013	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.008	0.048	0.009	0.008	0.008	0.008	0.008	0.048	0.009	0.008	0.008	0.008	0.008	0.048	0.009	0.008	0.008	0.008	0.008	0.048	0.009	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0005	0.0024	0.0005	0.0005	0.0005	0.0005	0.0005	0.0024	0.0005	0.0005	0.0005	0.0005	0.0005	0.0024	0.0005	0.0005	0.0005	0.0005	0.0005	0.0024	0.0005	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0003	0.0007	0.0002	0.0001	0.0001	0.0001	0.0003	0.0007	0.0002	0.0001	0.0001	0.0001	0.0003	0.0007	0.0002	0.0001	0.0001	0.0001	0.0003	0.0007	0.0002	0.0001
Silicon (Si)	mg/L	-	-	9	9	8	8	8	9	9	9	8	8	8	9	9	9	8	8	8	9	9	9	8	8	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.006	0.006	0.005	0.004	0.005	0.005	0.006	0.006	0.005	0.004	0.005	0.005	0.006	0.006	0.005	0.004	0.005	0.005	0.006	0.006	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.006	0.005	0.005	0.002	0.002	0.002	0.006	0.005	0.005	0.002	0.002	0.002	0.006	0.005	0.005	0.002	0.002	0.002	0.006	0.005	0.005	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002

Notes

1

World Health Organization (WH

Notes

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-4 Water Quality Results From Mine Area 500 m Downstream Clarification Pond Outlets (continued)

Ankaja River 500 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	35	35	39	36	42	45	35	35	39	36	42	45	35	35	39	36	42	45	35	35	39	36	42
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.4	1.5	1.5	1.6	1.5	1.5	1.4	1.5	1.5	1.6	1.5	1.5	1.4	1.5	1.5	1.6	1.5	1.5	1.4	1.5	1.5
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	3	3	4	4	4	4	3	3	4	4	4	4	3	3	4	4	4	4	3	3	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.3	2.3	2.3	2.3	2.5	2.6	2.3	2.3	2.3	2.3	2.5	2.6	2.3	2.3	2.3	2.3	2.5	2.6	2.3	2.3	2.3	2.3	2.5
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	7	7	7	8	8	7	7	7	7	8	8	7	7	7	7	8	8	7	7	7	7	8
Potassium (K)	mg/L	-	-	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7
Sodium (Na)	mg/L	-	-	2.8	2.3	2.3	2.4	2.3	2.6	2.8	2.3	2.3	2.4	2.3	2.6	2.8	2.3	2.3	2.4	2.3	2.6	2.8	2.3	2.3	2.4	2.3	2.6
Sulphate (SO ₄)	mg/L	-	-	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0023	0.0023	0.0021	0.0024	0.0003	0.0003	0.0023	0.0023	0.0021	0.0024	0.0003	0.0003	0.0023	0.0023	0.0021	0.0024	0.0003	0.0003	0.0023	0.0023	0.0021	0.0024	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0008	0.0007	0.0003	0.0008	0.0002	0.0002	0.0008	0.0007	0.0003	0.0008	0.0002	0.0002	0.0008	0.0007	0.0003	0.0008	0.0002	0.0002	0.0008	0.0007	0.0003	0.0008	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.031	0.029	0.012	0.029	0.012	0.013	0.031	0.029	0.012	0.029	0.012	0.013	0.031	0.029	0.012	0.029	0.012	0.013	0.031	0.029	0.012	0.029	0.012
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.045	0.038	0.007	0.045	0.007	0.008	0.045	0.038	0.007	0.045	0.007	0.008	0.045	0.038	0.007	0.045	0.007	0.008	0.045	0.038	0.007	0.045	0.007
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Iron (Fe)	mg/L	-	-	1.4	1.1	1.1	1.2	1.1	1.3	1.4	1.1	1.1	1.2	1.1	1.3	1.4	1.1	1.1	1.2	1.1	1.3	1.4	1.1	1.1	1.2	1.1	1.3
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.006	0.006	0.005	0.005	0.005	0.005	0.006	0.006	0.005	0.005	0.005	0.005	0.006	0.006	0.005	0.005	0.005	0.005	0.006	0.006	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.06	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0024	0.0022	0.0004	0.0023	0.0005	0.0005	0.0024	0.0022	0.0004	0.0023	0.0005	0.0005	0.0024	0.0022	0.0004	0.0023	0.0005	0.0005	0.0024	0.0022	0.0004	0.0023	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.007	0.006	0.007	0.008	0.006	0.006	0.007	0.006	0.007	0.008	0.006	0.006	0.007	0.006	0.007	0.008	0.006	0.006	0.007	0.006	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0007	0.0007	0.0003	0.0007	0.0001	0.0001	0.0007	0.0007	0.0003	0.0007	0.0001	0.0001	0.0007	0.0007	0.0003	0.0007	0.0001	0.0001	0.0007	0.0007	0.0003	0.0007	0.0001
Silicon (Si)	mg/L	-	-	9	7	7	8	7	8	9	7	7	8	7	8	9	7	7	8	7	8	9	7	7	8	7	8
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.006	0.005	0.006	0.004	0.005	0.006	0.006	0.005	0.006	0.004	0.005	0.006	0.006	0.005	0.006	0.004	0.005	0.006	0.006	0.005	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.006	0.006	0.005	0.006	0.002	0.002	0.006	0.006	0.005	0.006	0.002	0.002	0.006	0.006	0.005	0.006	0.002	0.002	0.006	0.006	0.005	0.006	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002

Notes

1

World Health Organization (WH)Notes

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-4 Water Quality Results From Mine Area 500 m Downstream Clarification Pond Outlets (continued)

Antsahalava River 500 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	32	29	32	31	44	45	32	29	32	31	44	45	32	29	32	31	44	33	24	22	24	23	32
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.03	0.04	0.03	0.05	0.05	0.04	0.03	0.04	0.03	0.05	0.05	0.04	0.03	0.04	0.03	0.05	0.18	0.12	0.11	0.12	0.11	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.4	1.4	1.5	1.5	1.5	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.04	0.04	0.04	0.04	0.05
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.3	2.3	2.3	2.3	2.6	2.6	2.3	2.3	2.3	2.3	2.6	2.6	2.3	2.3	2.3	2.3	2.6	3.2	2.7	2.6	2.7	2.7	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05
Magnesium (Mg)	mg/L	-	-	8	6	5	6	6	8	8	6	5	6	6	8	8	6	5	6	6	8	7	5	5	5	5	7
Potassium (K)	mg/L	-	-	0.8	0.6	0.5	0.6	0.5	0.8	0.8	0.6	0.5	0.6	0.5	0.8	0.8	0.6	0.5	0.6	0.5	0.8	0.9	0.6	0.6	0.6	0.6	0.9
Sodium (Na)	mg/L	-	-	2.8	2.9	3.0	2.9	2.9	2.7	2.8	2.9	3.0	2.9	2.9	2.7	2.8	2.9	3.0	2.9	2.9	2.7	1.3	1.9	2.2	1.9	2.0	1.3
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	2	2	3	2	3	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0026	0.0030	0.0028	0.0029	0.0003	0.0003	0.0026	0.0030	0.0028	0.0029	0.0003	0.0003	0.0026	0.0030	0.0028	0.0029	0.0003	0.0500	0.0365	0.0325	0.0361	0.0343	0.0496
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0013	0.0017	0.0014	0.0015	0.0002	0.0002	0.0013	0.0017	0.0014	0.0015	0.0002	0.0002	0.0013	0.0017	0.0014	0.0015	0.0002	0.0055	0.0049	0.0049	0.0049	0.0049	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.069	0.095	0.072	0.080	0.013	0.013	0.069	0.095	0.072	0.080	0.013	0.013	0.069	0.095	0.072	0.080	0.013	0.025	0.078	0.103	0.081	0.092	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.007	0.006	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0050	0.0037	0.0033	0.0036	0.0034	0.0050
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.022	0.023	0.022	0.022	0.008	0.008	0.022	0.023	0.022	0.022	0.008	0.008	0.022	0.023	0.022	0.022	0.008	0.006	0.021	0.022	0.021	0.022	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.005	0.004	0.003	0.004	0.003	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.004	0.003	0.004	0.003	0.005
Iron (Fe)	mg/L	-	-	1.4	1.0	0.9	1.0	1.0	1.4	1.4	1.0	0.9	1.0	1.0	1.4	1.4	1.0	0.9	1.0	1.0	1.4	1.1	0.8	0.7	0.8	0.8	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.050	0.035	0.031	0.035	0.033	0.050
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.04	0.05	0.05	0.06	0.06	0.05	0.04	0.05	0.05	0.06	0.06	0.05	0.04	0.05	0.05	0.06	0.07	0.05	0.05	0.05	0.05	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0001	0.0002	0.0001	0.0002	0.0002	0.0002	0.0001	0.0002	0.0001	0.0002	0.0002	0.0002	0.0001	0.0002	0.0001	0.0002	0.0005	0.0004	0.0003	0.0004	0.0004	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0048	0.0065	0.0050	0.0055	0.0005	0.0005	0.0048	0.0065	0.0050	0.0055	0.0005	0.0005	0.0048	0.0065	0.0050	0.0055	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0013	0.0017	0.0013	0.0015	0.0001	0.0001	0.0013	0.0017	0.0013	0.0015	0.0001	0.0001	0.0013	0.0017	0.0013	0.0015	0.0001	0.0050	0.0046	0.0047	0.0047	0.0047	0.0050
Silicon (Si)	mg/L	-	-	9	6	6	6	6	9	9	6	6	6	6	9	9	6	6	6	6	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.007	0.007	0.007	0.004	0.005	0.006	0.007	0.007	0.007	0.004	0.005	0.006	0.007	0.007	0.007	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.006	0.007	0.006	0.007	0.002	0.002	0.006	0.007	0.006	0.007	0.002	0.002	0.006	0.007	0.006	0.007	0.002	0.100	0.073	0.065	0.072	0.069	0.099
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.004	0.003	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.005	0.006	0.005	0.005	0.002	0.003	0.005	0.006	0.005	0.005	0.002	0.003	0.005	0.006	0.005	0.005	0.002	0.014	0.012	0.012	0.012	0.012	0.014

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water

Notes

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-4 Water Quality Results From Mine Area 500 m Downstream Clarification Pond Outlets (continued)

Sahaviara River 500 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	31	31	26	29	44	45	31	31	26	29	44	45	31	31	26	28	44	33	23	23	19	21	32
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.03	0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.03	0.03	0.05	0.18	0.12	0.12	0.09	0.10	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.4	1.3	1.3	1.4	1.4	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.04	0.04	0.04	0.04	0.05
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.1	2.1	2.1	2.1	2.6	2.6	2.1	2.1	2.1	2.1	2.6	2.6	2.1	2.1	2.1	2.1	2.6	3.2	2.5	2.5	2.3	2.4	3.1
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	6	6	5	5	8	8	6	6	5	5	8	8	6	6	5	5	8	7	5	5	4	4	7
Potassium (K)	mg/L	-	-	0.8	0.5	0.5	0.4	0.5	0.7	0.8	0.5	0.5	0.4	0.5	0.7	0.8	0.5	0.5	0.4	0.5	0.7	0.9	0.6	0.6	0.5	0.5	0.9
Sodium (Na)	mg/L	-	-	2.8	2.6	2.6	2.8	2.7	2.7	2.8	2.6	2.6	2.8	2.7	2.7	2.8	2.6	2.6	2.8	2.7	2.7	1.3	1.6	1.6	2.1	1.9	1.3
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	2	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0021	0.0019	0.0024	0.0020	0.0003	0.0003	0.0021	0.0019	0.0024	0.0020	0.0003	0.0003	0.0021	0.0019	0.0024	0.0021	0.0003	0.0500	0.0348	0.0344	0.0284	0.0308	0.0489
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0010	0.0010	0.0016	0.0013	0.0002	0.0002	0.0010	0.0010	0.0016	0.0013	0.0002	0.0002	0.0010	0.0010	0.0016	0.0013	0.0002	0.0055	0.0045	0.0045	0.0044	0.0044	0.0053
Barium (Ba)	mg/L	0.7	-	0.013	0.055	0.055	0.093	0.072	0.013	0.013	0.055	0.055	0.093	0.072	0.013	0.013	0.055	0.055	0.094	0.075	0.013	0.025	0.064	0.065	0.104	0.086	0.024
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.005	0.005	0.005	0.005	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0035	0.0034	0.0028	0.0031	0.0049
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.016	0.016	0.017	0.016	0.008	0.008	0.016	0.016	0.017	0.016	0.008	0.008	0.016	0.016	0.017	0.017	0.008	0.006	0.015	0.015	0.017	0.016	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.005	0.003	0.003	0.003	0.003	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005	0.005	0.003	0.003	0.003	0.003	0.005
Iron (Fe)	mg/L	-	-	1.4	1.0	1.0	0.8	0.9	1.4	1.4	1.0	1.0	0.8	0.9	1.4	1.4	1.0	1.0	0.8	0.9	1.4	1.1	0.8	0.8	0.6	0.7	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.050	0.034	0.034	0.027	0.030	0.049
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.04	0.04	0.06	0.06	0.05	0.05	0.04	0.04	0.06	0.06	0.05	0.05	0.04	0.04	0.06	0.07	0.05	0.05	0.04	0.04	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0005	0.0004	0.0004	0.0003	0.0003	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0037	0.0036	0.0062	0.0048	0.0005	0.0005	0.0037	0.0036	0.0062	0.0048	0.0005	0.0005	0.0037	0.0036	0.0062	0.0050	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.005	0.005	0.008	0.008	0.006	0.006	0.005	0.005	0.008	0.008	0.006	0.006	0.005	0.005	0.008	0.008	0.006	0.006	0.005	0.005	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0010	0.0010	0.0016	0.0012	0.0001	0.0001	0.0010	0.0010	0.0016	0.0012	0.0001	0.0001	0.0010	0.0010	0.0016	0.0013	0.0001	0.0050	0.0042	0.0042	0.0042	0.0042	0.0049
Silicon (Si)	mg/L	-	-	9	6	6	5	6	9	9	6	6	5	6	9	9	6	6	5	6	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.005	0.006	0.006	0.004	0.005	0.006	0.005	0.006	0.006	0.004	0.005	0.006	0.005	0.006	0.006	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.005	0.005	0.006	0.005	0.002	0.002	0.005	0.005	0.006	0.005	0.002	0.002	0.005	0.005	0.006	0.005	0.002	0.100	0.070	0.069	0.057	0.062	0.098
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.004	0.004	0.003	0.003	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.004	0.004	0.005	0.005	0.002	0.003	0.004	0.004	0.005	0.005	0.002	0.003	0.004	0.004	0.005	0.005	0.002	0.014	0.011	0.011	0.011	0.011	0.013

- Notes
- 1

World Health Organization (WHO) 2004 Guidelines for drinking water

Notes
- 2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.
- 3

Based on the un-ionized portion of ammonia.
- 4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.
- 5

Based on long-term exposure.
- 6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.
- 7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.
- 8

Based on an alkalinity value of less than 60 mg/L.
- 9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).
- 10

Based on the dissolved form of this metal.
- 11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.
- 12

Based on a dissolved saturation of at least 80%.
- 13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.
- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-4 Water Quality Results From Mine Area 500 m Downstream Clarification Pond Outlets (continued)

Sahamarirana River 500 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	28	28	33	32	41	45	28	28	33	32	41	45	28	28	33	32	41	33	21	21	24	23	30
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.03	0.03	0.04	0.04	0.05	0.05	0.03	0.03	0.04	0.04	0.05	0.05	0.03	0.03	0.04	0.04	0.05	0.18	0.11	0.10	0.12	0.12	0.16
Nitrate (NO ₃)	mg/L	50	-	1.6	1.4	1.4	1.3	1.3	1.5	1.6	1.4	1.4	1.3	1.3	1.5	1.6	1.4	1.4	1.3	1.3	1.5	1.4	1.2	1.3	1.2	1.1	1.3
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.05	0.04	0.04	0.04	0.04	0.05
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.0	2.0	2.1	2.1	2.4	2.6	2.0	2.0	2.1	2.1	2.4	2.6	2.0	2.0	2.1	2.1	2.4	3.2	2.4	2.4	2.5	2.4	3.0
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05
Magnesium (Mg)	mg/L	-	-	8	5	5	6	6	8	8	5	5	6	6	8	8	5	5	6	6	8	7	5	5	5	5	6
Potassium (K)	mg/L	-	-	0.8	0.5	0.5	0.6	0.6	0.7	0.8	0.5	0.5	0.6	0.6	0.7	0.8	0.5	0.5	0.6	0.6	0.7	0.9	0.6	0.6	0.7	0.6	0.8
Sodium (Na)	mg/L	-	-	2.8	2.4	2.5	2.3	2.3	2.5	2.8	2.4	2.5	2.3	2.3	2.5	2.8	2.4	2.5	2.3	2.3	2.5	1.3	1.6	1.6	1.3	1.3	1.2
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	1	1	1	2	2	2	1	1	1	2	2	2	1	1	2	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0024	0.0024	0.0019	0.0019	0.0003	0.0003	0.0024	0.0024	0.0019	0.0019	0.0003	0.0003	0.0024	0.0024	0.0019	0.0019	0.0003	0.0500	0.0319	0.0317	0.0367	0.0350	0.0459
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0011	0.0011	0.0006	0.0007	0.0001	0.0002	0.0011	0.0011	0.0006	0.0007	0.0001	0.0002	0.0011	0.0011	0.0006	0.0007	0.0001	0.0055	0.0042	0.0043	0.0043	0.0042	0.0050
Barium (Ba)	mg/L	0.7	-	0.013	0.054	0.057	0.031	0.034	0.012	0.013	0.054	0.057	0.031	0.034	0.012	0.013	0.054	0.057	0.031	0.034	0.012	0.025	0.061	0.064	0.039	0.044	0.023
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.005	0.005	0.005	0.005	0.006
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0032	0.0032	0.0037	0.0035	0.0046
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.024	0.023	0.013	0.010	0.007	0.008	0.024	0.023	0.013	0.010	0.007	0.008	0.024	0.023	0.013	0.010	0.007	0.006	0.023	0.023	0.012	0.009	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.005	0.003	0.003	0.004	0.003	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.003	0.003	0.004	0.003	0.004	0.005	0.003	0.003	0.004	0.003	0.004	0.005	0.003	0.003	0.004	0.003	0.004	0.005	0.003	0.003	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	0.9	0.9	1.0	1.0	1.3	1.4	0.9	0.9	1.0	1.0	1.3	1.4	0.9	0.9	1.0	1.0	1.3	1.1	0.7	0.7	0.8	0.8	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.050	0.031	0.031	0.036	0.035	0.046
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.04	0.04	0.05	0.05	0.06	0.06	0.04	0.04	0.05	0.05	0.06	0.06	0.04	0.04	0.05	0.05	0.06	0.07	0.05	0.05	0.05	0.05	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0005	0.0003	0.0003	0.0004	0.0004	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0039	0.0041	0.0020	0.0021	0.0005	0.0005	0.0039	0.0041	0.0020	0.0021	0.0005	0.0005	0.0039	0.0041	0.0020	0.0021	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.005	0.005	0.006	0.006	0.007	0.008	0.005	0.005	0.006	0.006	0.007	0.008	0.005	0.005	0.006	0.006	0.007	0.008	0.005	0.005	0.006	0.006	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0011	0.0011	0.0006	0.0006	0.0001	0.0001	0.0011	0.0011	0.0006	0.0006	0.0001	0.0001	0.0011	0.0011	0.0006	0.0006	0.0001	0.0050	0.0040	0.0040	0.0040	0.0039	0.0046
Silicon (Si)	mg/L	-	-	9	6	6	7	7	8	9	6	6	7	7	8	9	6	6	7	7	8	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.006	0.005	0.005	0.004	0.005	0.006	0.006	0.005	0.005	0.004	0.005	0.006	0.006	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.006	0.006	0.005	0.005	0.002	0.002	0.006	0.006	0.005	0.005	0.002	0.002	0.006	0.006	0.005	0.005	0.002	0.100	0.064	0.063	0.073	0.070	0.092
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.003	0.003	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.004	0.004	0.003	0.003	0.002	0.003	0.004	0.004	0.003	0.003	0.002	0.003	0.004	0.004	0.003	0.003	0.002	0.014	0.011	0.011	0.011	0.011	0.013

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water

Notes

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-4 Water Quality Results From Mine Area 500 m Downstream Clarification Pond Outlets (continued)

Torotorofotsy River 500 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	37	41	38	44	45	45	37	41	38	44	45	45	37	41	38	44	33	33	28	29	29	32
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.04	0.05	0.04	0.05	0.05	0.05	0.04	0.05	0.04	0.05	0.05	0.05	0.04	0.05	0.04	0.05	0.18	0.18	0.14	0.15	0.15	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.4	1.4	1.4	1.3	1.4	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.4	2.5	2.5	2.6	2.6	2.6	2.4	2.5	2.5	2.6	2.6	2.6	2.4	2.5	2.5	2.6	3.2	3.2	2.9	3.0	3.0	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	8	8	7	8	7	8	8	8	7	8	7	8	8	8	7	8	7	8	7	7	6	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.8	0.6	0.7	0.7	0.8	0.8	0.8	0.6	0.7	0.7	0.8	0.8	0.8	0.6	0.7	0.7	0.8	0.9	0.9	0.8	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7	1.3	1.3	1.3	1.3	1.3	1.3
Sulphate (SO ₄)	mg/L	-	-	1	1	2	1	2	1	1	1	2	1	2	1	1	1	2	1	2	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0024	0.0022	0.0022	0.0003	0.0003	0.0003	0.0024	0.0022	0.0022	0.0003	0.0003	0.0003	0.0024	0.0022	0.0022	0.0003	0.0500	0.0500	0.0426	0.0441	0.0438	0.0496
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0008	0.0004	0.0007	0.0002	0.0002	0.0002	0.0008	0.0004	0.0007	0.0002	0.0002	0.0002	0.0008	0.0004	0.0007	0.0002	0.0055	0.0055	0.0051	0.0051	0.0051	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.034	0.015	0.029	0.013	0.013	0.013	0.034	0.015	0.029	0.013	0.013	0.013	0.034	0.015	0.029	0.013	0.025	0.025	0.044	0.037	0.039	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.007	0.007	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0050	0.0050	0.0043	0.0044	0.0044	0.0050
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.046	0.012	0.042	0.008	0.008	0.008	0.046	0.012	0.042	0.008	0.008	0.008	0.046	0.012	0.042	0.008	0.006	0.006	0.044	0.031	0.041	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.004	0.004	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.2	1.3	1.2	1.4	1.4	1.4	1.2	1.3	1.2	1.4	1.4	1.4	1.2	1.3	1.2	1.4	1.1	1.1	1.0	1.0	1.0	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.006	0.006	0.006	0.005	0.005	0.005	0.006	0.006	0.006	0.005	0.005	0.005	0.006	0.006	0.006	0.005	0.050	0.050	0.042	0.044	0.043	0.050
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0004	0.0004	0.0004	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0026	0.0007	0.0022	0.0005	0.0005	0.0005	0.0026	0.0007	0.0022	0.0005	0.0005	0.0005	0.0026	0.0007	0.0022	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0008	0.0003	0.0006	0.0001	0.0001	0.0001	0.0008	0.0003	0.0006	0.0001	0.0001	0.0001	0.0008	0.0003	0.0006	0.0001	0.0050	0.0050	0.0047	0.0047	0.0048	0.0050
Silicon (Si)	mg/L	-	-	9	9	8	8	8	9	9	9	8	8	8	9	9	9	8	8	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.006	0.006	0.006	0.004	0.005	0.005	0.006	0.006	0.006	0.004	0.005	0.005	0.006	0.006	0.006	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.006	0.006	0.006	0.002	0.002	0.002	0.006	0.006	0.006	0.002	0.002	0.002	0.006	0.006	0.006	0.002	0.100	0.100	0.085	0.088	0.088	0.099
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.004	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.014	0.014	0.012	0.012	0.013	0.014

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water

Notes

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-4 Water Quality Results From Mine Area 500 m Downstream Clarification Pond Outlets (continued)

Sakalava River 500 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	41	37	41	44	45	45	41	37	41	44	45	45	41	37	41	44	33	33	29	28	29	32
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.18	0.18	0.15	0.14	0.15	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6	1.4	1.4	1.3	1.4	1.3	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.5	2.4	2.4	2.6	2.6	2.6	2.5	2.4	2.4	2.6	2.6	2.6	2.5	2.4	2.4	2.6	3.2	3.2	2.9	2.9	2.9	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	7	8	8	8	8	8	7	8	8	8	8	8	7	8	8	7	7	6	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7	0.9	0.9	0.8	0.7	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7	1.3	1.3	1.2	1.3	1.2	1.3
Sulphate (SO ₄)	mg/L	-	-	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0022	0.0020	0.0017	0.0003	0.0003	0.0003	0.0022	0.0020	0.0017	0.0003	0.0003	0.0003	0.0022	0.0020	0.0017	0.0003	0.0500	0.0500	0.0441	0.0423	0.0447	0.0493
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0003	0.0007	0.0003	0.0002	0.0002	0.0002	0.0003	0.0007	0.0003	0.0002	0.0002	0.0002	0.0003	0.0007	0.0003	0.0002	0.0055	0.0055	0.0050	0.0050	0.0050	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.013	0.031	0.013	0.013	0.013	0.013	0.013	0.031	0.013	0.013	0.013	0.013	0.013	0.031	0.013	0.013	0.025	0.025	0.033	0.041	0.030	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.007	0.007	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0050	0.0050	0.0044	0.0042	0.0045	0.0049
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.008	0.048	0.009	0.008	0.008	0.008	0.008	0.048	0.009	0.008	0.008	0.008	0.008	0.048	0.009	0.008	0.006	0.006	0.028	0.046	0.018	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.005	0.005	0.004	0.004	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4	1.1	1.1	1.0	1.0	1.0	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.050	0.050	0.044	0.042	0.045	0.049
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0004	0.0004	0.0004	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0005	0.0024	0.0005	0.0005	0.0005	0.0005	0.0005	0.0024	0.0005	0.0005	0.0005	0.0005	0.0005	0.0024	0.0005	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0003	0.0007	0.0002	0.0001	0.0001	0.0001	0.0003	0.0007	0.0002	0.0001	0.0001	0.0001	0.0003	0.0007	0.0002	0.0001	0.0050	0.0050	0.0047	0.0047	0.0046	0.0049
Silicon (Si)	mg/L	-	-	9	9	8	8	8	9	9	9	8	8	8	9	9	9	8	8	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.006	0.006	0.005	0.004	0.005	0.005	0.006	0.006	0.005	0.004	0.005	0.005	0.006	0.006	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.006	0.005	0.005	0.002	0.002	0.002	0.006	0.005	0.005	0.002	0.002	0.002	0.006	0.005	0.005	0.002	0.100	0.100	0.088	0.085	0.089	0.099
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.004	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.014	0.014	0.012	0.012	0.012	0.014

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water

Notes

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-4 Water Quality Results From Mine Area 500 m Downstream Clarification Pond Outlets (continued)

Ankaja River 500 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	35	35	39	36	42	45	35	35	39	36	42	45	35	35	39	36	42	33	26	26	27	26	31
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.18	0.14	0.13	0.14	0.14	0.16
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.4	1.5	1.5	1.6	1.5	1.5	1.4	1.5	1.5	1.6	1.5	1.5	1.4	1.5	1.5	1.4	1.3	1.3	1.3	1.3	1.3
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.04	0.04	0.04	0.04	0.05
Calcium (Ca)	mg/L	-	-	4	3	3	4	4	4	4	3	3	4	4	4	4	3	3	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.3	2.3	2.3	2.3	2.5	2.6	2.3	2.3	2.3	2.3	2.5	2.6	2.3	2.3	2.3	2.3	2.5	3.2	2.7	2.7	2.8	2.8	3.0
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	7	7	7	8	8	7	7	7	7	8	8	7	7	7	7	8	7	6	6	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7	0.9	0.7	0.7	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	2.8	2.3	2.3	2.4	2.3	2.6	2.8	2.3	2.3	2.4	2.3	2.6	2.8	2.3	2.3	2.4	2.3	2.6	1.3	1.2	1.2	1.2	1.2	1.2
Sulphate (SO ₄)	mg/L	-	-	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	2	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0023	0.0023	0.0021	0.0024	0.0003	0.0003	0.0023	0.0023	0.0021	0.0024	0.0003	0.0003	0.0023	0.0023	0.0021	0.0024	0.0003	0.0500	0.0402	0.0400	0.0410	0.0405	0.0470
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0008	0.0007	0.0003	0.0008	0.0002	0.0002	0.0008	0.0007	0.0003	0.0008	0.0002	0.0002	0.0008	0.0007	0.0003	0.0008	0.0002	0.0055	0.0048	0.0047	0.0048	0.0048	0.0051
Barium (Ba)	mg/L	0.7	-	0.013	0.031	0.029	0.012	0.029	0.012	0.013	0.031	0.029	0.012	0.029	0.012	0.013	0.031	0.029	0.012	0.029	0.012	0.025	0.040	0.038	0.036	0.039	0.023
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.006	0.006	0.006	0.006	0.006
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0050	0.0040	0.0040	0.0041	0.0041	0.0047
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.045	0.038	0.007	0.045	0.007	0.008	0.045	0.038	0.007	0.045	0.007	0.008	0.045	0.038	0.007	0.045	0.007	0.006	0.044	0.037	0.038	0.043	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.005	0.004	0.004	0.004	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.1	1.1	1.2	1.1	1.3	1.4	1.1	1.1	1.2	1.1	1.3	1.4	1.1	1.1	1.2	1.1	1.3	1.1	0.9	0.9	0.9	0.9	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.006	0.006	0.005	0.005	0.005	0.005	0.006	0.006	0.005	0.005	0.005	0.005	0.006	0.006	0.005	0.050	0.040	0.040	0.041	0.040	0.047
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.06	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.06	0.07	0.06	0.06	0.06	0.06	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0024	0.0022	0.0004	0.0023	0.0005	0.0005	0.0024	0.0022	0.0004	0.0023	0.0005	0.0005	0.0024	0.0022	0.0005	0.0023	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.007	0.006	0.007	0.008	0.006	0.006	0.007	0.006	0.007	0.008	0.006	0.006	0.007	0.006	0.007	0.008	0.007	0.007	0.007	0.007	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0007	0.0007	0.0003	0.0007	0.0001	0.0001	0.0007	0.0007	0.0003	0.0007	0.0001	0.0001	0.0007	0.0007	0.0003	0.0007	0.0001	0.0050	0.0045	0.0044	0.0045	0.0045	0.0047
Silicon (Si)	mg/L	-	-	9	7	7	8	7	8	9	7	7	8	7	8	9	7	7	8	7	8	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.006	0.005	0.006	0.004	0.005	0.006	0.006	0.005	0.006	0.004	0.005	0.006	0.006	0.006	0.006	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.006	0.006	0.005	0.006	0.002	0.002	0.006	0.006	0.005	0.006	0.002	0.002	0.006	0.006	0.005	0.006	0.002	0.100	0.080	0.080	0.082	0.081	0.094
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.004	0.004	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.014	0.012	0.011	0.012	0.012	0.013

- Notes
- 1

World Health Organization (WHO) 2004 Guidelines for drinking water

Notes
- 2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.
- 3

Based on the un-ionized portion of ammonia.
- 4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.
- 5

Based on long-term exposure.
- 6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.
- 7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.
- 8

Based on an alkalinity value of less than 60 mg/L.
- 9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).
- 10

Based on the dissolved form of this metal.
- 11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.
- 12

Based on a dissolved saturation of at least 80%.
- 13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.
- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-5 Water Quality Results From Mine Area 1,000 m Downstream of Clarification Pond Outlets

Antsahalava River 1,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	25	22	24	23	33	33	25	22	24	23	33	33	25	22	24	23	33	45	33	30	33	32	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.12	0.11	0.12	0.11	0.17	0.18	0.12	0.11	0.12	0.11	0.17	0.18	0.12	0.11	0.12	0.12	0.17	0.05	0.04	0.03	0.04	0.03	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.5	1.5	1.5	1.4	1.4	1.4	1.5	1.5	1.5	1.4	1.4	1.4	1.5	1.5	1.5	1.4	1.6	1.6	1.7	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	3.2	2.7	2.6	2.7	2.7	3.2	3.2	2.7	2.6	2.7	2.7	3.2	3.2	2.7	2.6	2.7	2.7	3.2	2.6	2.3	2.3	2.3	2.3	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05
Magnesium (Mg)	mg/L	-	-	7	5	5	5	5	7	7	5	5	5	5	7	7	5	5	5	5	7	8	6	5	6	6	8
Potassium (K)	mg/L	-	-	0.9	0.7	0.6	0.7	0.6	0.9	0.9	0.7	0.6	0.7	0.6	0.9	0.9	0.7	0.6	0.7	0.6	0.9	0.8	0.6	0.5	0.6	0.5	0.8
Sodium (Na)	mg/L	-	-	1.3	1.8	2.1	1.9	2.0	1.3	1.3	1.8	2.1	1.9	2.0	1.3	1.3	1.8	2.1	1.9	2.0	1.3	2.8	2.9	3.0	2.9	2.9	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	3	2	2	2	2	2	3	2	2	2	2	2	3	2	2	2	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0372	0.0332	0.0367	0.0348	0.0496	0.0500	0.0372	0.0333	0.0367	0.0350	0.0496	0.0500	0.0372	0.0333	0.0368	0.0354	0.0496	0.0003	0.0025	0.0029	0.0026	0.0027	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0050	0.0049	0.0050	0.0049	0.0054	0.0055	0.0050	0.0049	0.0050	0.0049	0.0054	0.0055	0.0050	0.0049	0.0050	0.0049	0.0054	0.0002	0.0013	0.0017	0.0013	0.0014	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.075	0.100	0.079	0.090	0.025	0.025	0.075	0.100	0.079	0.089	0.025	0.025	0.075	0.100	0.079	0.087	0.025	0.013	0.067	0.091	0.069	0.077	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.005	0.005	0.005	0.005	0.005	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0037	0.0033	0.0037	0.0035	0.0050	0.0050	0.0037	0.0033	0.0037	0.0035	0.0050	0.0050	0.0037	0.0033	0.0037	0.0035	0.0050	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.020	0.022	0.020	0.021	0.006	0.006	0.020	0.022	0.020	0.021	0.006	0.006	0.020	0.021	0.020	0.021	0.006	0.008	0.021	0.022	0.021	0.021	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.004	0.003	0.004	0.003	0.005	0.005	0.004	0.003	0.004	0.003	0.005	0.005	0.004	0.003	0.004	0.003	0.005	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.003	0.004	0.003	0.005	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.003	0.005
Iron (Fe)	mg/L	-	-	1.1	0.8	0.7	0.8	0.8	1.1	1.1	0.8	0.7	0.8	0.8	1.1	1.1	0.8	0.7	0.8	0.8	1.1	1.4	1.0	0.9	1.0	1.0	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.036	0.032	0.036	0.034	0.050	0.050	0.036	0.032	0.036	0.034	0.050	0.050	0.036	0.032	0.036	0.034	0.050	0.005	0.005	0.004	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.05	0.05	0.05	0.05	0.07	0.07	0.05	0.05	0.05	0.05	0.07	0.07	0.05	0.05	0.05	0.05	0.07	0.06	0.05	0.04	0.05	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0004	0.0003	0.0004	0.0004	0.0005	0.0005	0.0004	0.0003	0.0004	0.0004	0.0005	0.0005	0.0004	0.0003	0.0004	0.0004	0.0005	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0046	0.0062	0.0047	0.0052	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0047	0.0047	0.0047	0.0047	0.0050	0.0050	0.0047	0.0047	0.0047	0.0047	0.0050	0.0050	0.0047	0.0047	0.0047	0.0047	0.0050	0.0001	0.0012	0.0016	0.0013	0.0014	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	7	6	7	6	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.006	0.007	0.006	0.007	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.074	0.066	0.073	0.070	0.099	0.100	0.074	0.067	0.073	0.070	0.099	0.100	0.074	0.067	0.074	0.071	0.099	0.002	0.006	0.007	0.006	0.006	0.002
Vanadium (V)	mg/L	-	-	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.013	0.013	0.013	0.012	0.014	0.014	0.013	0.013	0.013	0.012	0.014	0.014	0.013	0.013	0.013	0.013	0.014	0.003	0.005	0.006	0.005	0.005	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-5 Water Quality Results From Mine Area 1,000 m Downstream of Clarification Pond Outlets (continued)

Sahaviara River 1,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	ost-closur	Baseline	Year 4	Year 10	Year 15	Year 20	ost-closur	Baseline	Year 4	Year 10	Year 15	Year 20	ost-closur	Baseline	Year 4	Year 10	Year 15	Year 20	ost-closur
Total Alkalinity as CaCO ₃	mg/L	-	-	33	25	24	21	22	32	33	25	24	21	22	32	33	25	24	21	23	32	45	33	33	29	32	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.13	0.12	0.10	0.11	0.17	0.18	0.13	0.12	0.11	0.11	0.17	0.18	0.13	0.13	0.11	0.11	0.17	0.05	0.04	0.04	0.03	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.3	1.3	1.4	1.4	1.4	1.4	1.3	1.3	1.4	1.4	1.4	1.4	1.3	1.3	1.4	1.4	1.4	1.6	1.5	1.5	1.6	1.5	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	3.2	2.6	2.6	2.5	2.5	3.2	3.2	2.6	2.6	2.5	2.5	3.2	3.2	2.6	2.6	2.5	2.5	3.2	2.6	2.2	2.2	2.2	2.2	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	5	5	4	5	7	7	5	5	4	5	7	7	5	5	4	5	7	8	6	6	5	6	8
Potassium (K)	mg/L	-	-	0.9	0.7	0.7	0.6	0.6	0.9	0.9	0.7	0.7	0.6	0.6	0.9	0.9	0.7	0.7	0.6	0.6	0.9	0.8	0.6	0.6	0.5	0.5	0.7
Sodium (Na)	mg/L	-	-	1.3	1.5	1.6	1.9	1.8	1.3	1.3	1.5	1.6	1.9	1.8	1.3	1.3	1.5	1.6	1.9	1.8	1.3	2.8	2.6	2.6	2.8	2.7	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2	2	1	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0373	0.0369	0.0316	0.0338	0.0491	0.0500	0.0375	0.0369	0.0317	0.0339	0.0491	0.0500	0.0376	0.0371	0.0319	0.0341	0.0491	0.0003	0.0018	0.0016	0.0020	0.0017	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0047	0.0046	0.0046	0.0046	0.0054	0.0055	0.0047	0.0046	0.0046	0.0046	0.0054	0.0055	0.0047	0.0047	0.0046	0.0046	0.0054	0.0002	0.0009	0.0009	0.0014	0.0011	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.057	0.058	0.092	0.076	0.025	0.025	0.057	0.058	0.091	0.076	0.025	0.025	0.057	0.058	0.091	0.076	0.025	0.013	0.048	0.047	0.079	0.062	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0037	0.0037	0.0032	0.0034	0.0049	0.0050	0.0037	0.0037	0.0032	0.0034	0.0049	0.0050	0.0038	0.0037	0.0032	0.0034	0.0049	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.013	0.014	0.015	0.015	0.006	0.006	0.013	0.013	0.015	0.015	0.006	0.006	0.013	0.013	0.015	0.015	0.006	0.008	0.014	0.014	0.016	0.015	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.004	0.004	0.003	0.003	0.005	0.005	0.004	0.004	0.003	0.003	0.005	0.005	0.004	0.004	0.003	0.003	0.005	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.003	0.003	0.005	0.005	0.004	0.004	0.003	0.003	0.005	0.005	0.004	0.004	0.003	0.003	0.005	0.005	0.004	0.004	0.003	0.003	0.005
Iron (Fe)	mg/L	-	-	1.1	0.8	0.8	0.7	0.8	1.1	1.1	0.8	0.8	0.7	0.8	1.1	1.1	0.9	0.8	0.7	0.8	1.1	1.4	1.0	1.0	0.9	1.0	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.037	0.036	0.030	0.033	0.049	0.050	0.037	0.036	0.030	0.033	0.049	0.050	0.037	0.036	0.031	0.033	0.049	0.005	0.004	0.004	0.004	0.004	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.05	0.05	0.05	0.05	0.07	0.07	0.05	0.05	0.05	0.05	0.07	0.07	0.05	0.05	0.05	0.05	0.07	0.06	0.05	0.05	0.04	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0004	0.0004	0.0003	0.0003	0.0005	0.0005	0.0004	0.0004	0.0003	0.0003	0.0005	0.0005	0.0004	0.0004	0.0003	0.0004	0.0005	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0031	0.0031	0.0052	0.0040	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.005	0.006	0.008	0.008	0.006	0.006	0.005	0.006	0.008	0.008	0.006	0.006	0.005	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0044	0.0043	0.0044	0.0043	0.0049	0.0050	0.0044	0.0043	0.0044	0.0043	0.0049	0.0050	0.0044	0.0043	0.0044	0.0043	0.0049	0.0001	0.0008	0.0008	0.0013	0.0010	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	7	7	6	6	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.006	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.075	0.074	0.063	0.068	0.098	0.100	0.075	0.074	0.063	0.068	0.098	0.100	0.075	0.074	0.064	0.068	0.098	0.002	0.005	0.004	0.005	0.004	0.002
Vanadium (V)	mg/L	-	-	0.005	0.004	0.004	0.003	0.003	0.005	0.005	0.004	0.004	0.003	0.003	0.005	0.005	0.004	0.004	0.003	0.003	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.012	0.012	0.012	0.012	0.013	0.014	0.012	0.012	0.012	0.012	0.013	0.014	0.012	0.012	0.012	0.012	0.013	0.003	0.004	0.004	0.005	0.004	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-5 Water Quality Results From Mine Area 1,000 m Downstream of Clarification Pond Outlets (continued)

Sahamarirana River 1,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	22	22	25	24	30	33	22	22	25	24	30	33	22	22	25	24	30	45	29	29	33	33	41
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.11	0.11	0.13	0.12	0.16	0.18	0.11	0.11	0.13	0.12	0.16	0.18	0.11	0.11	0.13	0.12	0.16	0.05	0.03	0.03	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.2	1.3	1.2	1.2	1.3	1.4	1.2	1.3	1.2	1.2	1.3	1.4	1.2	1.3	1.2	1.2	1.3	1.6	1.4	1.4	1.4	1.4	1.5
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.02	0.02	0.02	0.02	0.02	0.01
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	3.2	2.4	2.4	2.5	2.5	3.0	3.2	2.4	2.4	2.5	2.5	3.0	3.2	2.4	2.4	2.5	2.4	3.0	2.6	2.0	2.1	2.1	2.1	2.4
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05
Magnesium (Mg)	mg/L	-	-	7	5	5	5	5	6	7	5	5	5	5	6	7	5	5	5	5	6	8	6	6	6	6	8
Potassium (K)	mg/L	-	-	0.9	0.6	0.6	0.7	0.6	0.8	0.9	0.6	0.6	0.7	0.6	0.8	0.9	0.6	0.6	0.7	0.6	0.8	0.8	0.5	0.5	0.6	0.6	0.7
Sodium (Na)	mg/L	-	-	1.3	1.5	1.6	1.3	1.3	1.2	1.3	1.5	1.6	1.3	1.3	1.2	1.3	1.5	1.6	1.3	1.3	1.2	2.8	2.5	2.5	2.3	2.4	2.5
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2	2	1	1	2	2	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0330	0.0327	0.0374	0.0361	0.0461	0.0500	0.0331	0.0328	0.0374	0.0359	0.0461	0.0500	0.0331	0.0329	0.0375	0.0358	0.0461	0.0003	0.0023	0.0023	0.0018	0.0018	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0043	0.0043	0.0044	0.0043	0.0050	0.0055	0.0043	0.0043	0.0044	0.0043	0.0050	0.0055	0.0043	0.0043	0.0044	0.0043	0.0050	0.0002	0.0010	0.0011	0.0006	0.0006	0.0001
Barium (Ba)	mg/L	0.7	-	0.025	0.059	0.062	0.039	0.043	0.023	0.025	0.059	0.062	0.039	0.043	0.023	0.025	0.059	0.062	0.039	0.043	0.023	0.013	0.051	0.054	0.030	0.033	0.012
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.005	0.005	0.005	0.005	0.006	0.007	0.005	0.005	0.005	0.005	0.006	0.007	0.005	0.005	0.005	0.005	0.006	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0033	0.0033	0.0037	0.0036	0.0046	0.0050	0.0033	0.0033	0.0037	0.0036	0.0046	0.0050	0.0033	0.0033	0.0038	0.0036	0.0046	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.022	0.022	0.011	0.009	0.006	0.006	0.022	0.022	0.011	0.009	0.006	0.006	0.022	0.021	0.011	0.009	0.006	0.008	0.023	0.022	0.012	0.010	0.007
Cobalt (Co)	mg/L	-	-	0.005	0.003	0.003	0.004	0.004	0.005	0.005	0.003	0.003	0.004	0.004	0.005	0.005	0.003	0.003	0.004	0.004	0.005	0.002	0.001	0.001	0.001	0.001	0.001
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.003	0.003	0.004	0.004	0.005	0.005	0.003	0.003	0.004	0.004	0.005	0.005	0.003	0.003	0.004	0.004	0.005	0.005	0.003	0.003	0.004	0.004	0.004
Iron (Fe)	mg/L	-	-	1.1	0.7	0.7	0.9	0.8	1.1	1.1	0.7	0.7	0.9	0.8	1.1	1.1	0.7	0.7	0.9	0.8	1.1	1.4	0.9	0.9	1.1	1.0	1.3
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.032	0.032	0.037	0.036	0.046	0.050	0.032	0.032	0.037	0.036	0.046	0.050	0.032	0.032	0.037	0.035	0.046	0.005	0.004	0.004	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.05	0.05	0.05	0.05	0.07	0.07	0.05	0.05	0.05	0.05	0.07	0.07	0.05	0.05	0.05	0.05	0.07	0.06	0.04	0.04	0.05	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0003	0.0003	0.0004	0.0004	0.0005	0.0005	0.0003	0.0003	0.0004	0.0004	0.0005	0.0005	0.0003	0.0003	0.0004	0.0004	0.0005	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0037	0.0038	0.0019	0.0020	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.005	0.005	0.006	0.006	0.007	0.008	0.005	0.005	0.006	0.006	0.007	0.008	0.005	0.005	0.006	0.006	0.007	0.008	0.005	0.005	0.006	0.006	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0041	0.0041	0.0041	0.0040	0.0046	0.0050	0.0041	0.0041	0.0041	0.0040	0.0046	0.0050	0.0041	0.0041	0.0041	0.0040	0.0046	0.0001	0.0010	0.0010	0.0005	0.0006	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	6	6	7	7	8
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.006	0.006	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.066	0.065	0.075	0.072	0.092	0.100	0.066	0.066	0.075	0.072	0.092	0.100	0.066	0.066	0.075	0.072	0.092	0.002	0.005	0.005	0.005	0.005	0.002
Vanadium (V)	mg/L	-	-	0.005	0.003	0.003	0.004	0.004	0.005	0.005	0.003	0.003	0.004	0.004	0.005	0.005	0.003	0.003	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.011	0.011	0.011	0.011	0.013	0.014	0.011	0.011	0.011	0.011	0.013	0.014	0.011	0.011	0.011	0.011	0.013	0.003	0.004	0.004	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-5 Water Quality Results From Mine Area 1,000 m Downstream of Clarification Pond Outlets (continued)

Torotorofotsy River 1,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	33	30	30	30	33	33	33	30	30	30	33	33	33	30	31	30	33	45	45	40	42	41	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.18	0.16	0.16	0.16	0.17	0.18	0.18	0.16	0.16	0.16	0.17	0.18	0.18	0.16	0.16	0.16	0.17	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.4	1.4	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.2	3.0	3.0	3.1	3.2	3.2	3.2	3.0	3.1	3.1	3.2	3.2	3.2	3.0	3.1	3.1	3.2	2.6	2.6	2.5	2.5	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	7	6	6	7	7	7	7	6	7	7	7	7	7	6	7	7	7	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.9	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.9	0.8	0.8	0.7	0.7	0.8	
Sodium (Na)	mg/L	-	-	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	2.8	2.8	2.6	2.6	2.6	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0500	0.0455	0.0460	0.0462	0.0498	0.0500	0.0500	0.0455	0.0465	0.0462	0.0498	0.0500	0.0500	0.0455	0.0472	0.0462	0.0498	0.0003	0.0003	0.0016	0.0014	0.0014	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0055	0.0052	0.0052	0.0053	0.0054	0.0055	0.0055	0.0052	0.0052	0.0053	0.0054	0.0055	0.0055	0.0052	0.0053	0.0053	0.0054	0.0002	0.0002	0.0006	0.0003	0.0005	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.025	0.037	0.034	0.033	0.025	0.025	0.025	0.037	0.032	0.033	0.025	0.025	0.025	0.037	0.029	0.033	0.025	0.013	0.013	0.026	0.014	0.023	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0050	0.0045	0.0046	0.0046	0.0050	0.0050	0.0050	0.0045	0.0047	0.0046	0.0050	0.0050	0.0050	0.0045	0.0047	0.0046	0.0050	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.006	0.030	0.025	0.028	0.006	0.006	0.006	0.030	0.021	0.028	0.006	0.006	0.006	0.030	0.015	0.028	0.006	0.008	0.008	0.031	0.010	0.029	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.4	1.4	1.3	1.3	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.050	0.045	0.046	0.046	0.050	0.050	0.050	0.045	0.046	0.046	0.050	0.050	0.050	0.045	0.047	0.046	0.050	0.005	0.005	0.005	0.006	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.07	0.06	0.07	0.07	0.07	0.07	0.07	0.06	0.07	0.07	0.07	0.07	0.07	0.06	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0005	0.0018	0.0006	0.0015	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0050	0.0048	0.0048	0.0049	0.0050	0.0050	0.0050	0.0048	0.0048	0.0049	0.0050	0.0050	0.0050	0.0048	0.0048	0.0049	0.0050	0.0001	0.0001	0.0005	0.0002	0.0004	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	9	8	9	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.006	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.100	0.091	0.092	0.092	0.100	0.100	0.100	0.091	0.093	0.092	0.100	0.100	0.100	0.091	0.094	0.092	0.100	0.002	0.002	0.004	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-5 Water Quality Results From Mine Area 1,000 m Downstream of Clarification Pond Outlets (continued)

Torotorofotsy River 1,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	33	30	30	30	33	33	33	30	30	30	33	33	33	30	31	30	33	45	45	40	42	41	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.18	0.16	0.16	0.16	0.17	0.18	0.18	0.16	0.16	0.16	0.17	0.18	0.18	0.16	0.16	0.16	0.17	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.4	1.4	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.2	3.0	3.0	3.1	3.2	3.2	3.2	3.0	3.1	3.1	3.2	3.2	3.2	3.0	3.1	3.1	3.2	2.6	2.6	2.5	2.5	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	7	7	6	6	7	7	7	7	6	7	7	7	7	7	6	7	7	7	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.9	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.9	0.8	0.8	0.7	0.7	0.8	
Sodium (Na)	mg/L	-	-	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	2.8	2.8	2.6	2.6	2.6	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0500	0.0455	0.0460	0.0462	0.0498	0.0500	0.0500	0.0455	0.0465	0.0462	0.0498	0.0500	0.0500	0.0455	0.0472	0.0462	0.0498	0.0003	0.0003	0.0016	0.0014	0.0014	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0055	0.0052	0.0052	0.0053	0.0054	0.0055	0.0055	0.0052	0.0052	0.0053	0.0054	0.0055	0.0055	0.0052	0.0053	0.0053	0.0054	0.0002	0.0002	0.0006	0.0003	0.0005	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.025	0.037	0.034	0.033	0.025	0.025	0.025	0.037	0.032	0.033	0.025	0.025	0.025	0.037	0.029	0.033	0.025	0.013	0.013	0.026	0.014	0.023	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0050	0.0045	0.0046	0.0046	0.0050	0.0050	0.0050	0.0045	0.0047	0.0046	0.0050	0.0050	0.0050	0.0045	0.0047	0.0046	0.0050	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.006	0.030	0.025	0.028	0.006	0.006	0.006	0.030	0.021	0.028	0.006	0.006	0.006	0.030	0.015	0.028	0.006	0.008	0.008	0.031	0.010	0.029	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.4	1.4	1.3	1.3	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.050	0.045	0.046	0.046	0.050	0.050	0.050	0.045	0.046	0.046	0.050	0.050	0.050	0.045	0.047	0.046	0.050	0.005	0.005	0.005	0.006	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.07	0.06	0.07	0.07	0.07	0.07	0.07	0.06	0.07	0.07	0.07	0.07	0.07	0.06	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0005	0.0018	0.0006	0.0015	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0050	0.0048	0.0048	0.0049	0.0050	0.0050	0.0050	0.0048	0.0048	0.0049	0.0050	0.0050	0.0050	0.0048	0.0048	0.0049	0.0050	0.0001	0.0001	0.0005	0.0002	0.0004	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	9	8	9	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.006	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.100	0.091	0.092	0.092	0.100	0.100	0.100	0.091	0.093	0.092	0.100	0.100	0.100	0.091	0.094	0.092	0.100	0.002	0.002	0.004	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-5 Water Quality Results From Mine Area 1,000 m Downstream of Clarification Pond Outlets (continued)

Ankaja River 1,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	27	27	28	27	31	33	27	27	28	27	31	33	27	27	28	27	31	45	37	37	40	37	42
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.14	0.14	0.14	0.14	0.17	0.18	0.14	0.14	0.14	0.14	0.17	0.18	0.14	0.14	0.15	0.14	0.17	0.05	0.04	0.04	0.05	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.6	1.5	1.5	1.4	1.5	1.5
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	2.8	2.8	2.8	2.8	3.1	3.2	2.8	2.8	2.8	2.8	3.1	3.2	2.8	2.8	2.8	2.8	3.1	2.6	2.3	2.3	2.4	2.4	2.5
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	7	6	6	6	6	7	7	6	6	6	6	7	7	6	6	6	6	7	8	7	7	7	7	8
Potassium (K)	mg/L	-	-	0.9	0.7	0.7	0.7	0.7	0.8	0.9	0.7	0.7	0.8	0.7	0.8	0.9	0.7	0.7	0.8	0.7	0.8	0.8	0.6	0.6	0.7	0.6	0.7
Sodium (Na)	mg/L	-	-	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.2	1.2	1.2	1.2	1.2	2.8	2.4	2.4	2.4	2.4	2.6
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2	2	1	1	2	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0418	0.0413	0.0422	0.0419	0.0475	0.0500	0.0418	0.0418	0.0424	0.0419	0.0475	0.0500	0.0418	0.0418	0.0428	0.0419	0.0475	0.0003	0.0019	0.0020	0.0018	0.0021	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0049	0.0049	0.0049	0.0049	0.0052	0.0055	0.0049	0.0049	0.0049	0.0049	0.0052	0.0055	0.0049	0.0049	0.0049	0.0049	0.0052	0.0002	0.0007	0.0006	0.0003	0.0007	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.037	0.038	0.035	0.037	0.024	0.025	0.037	0.036	0.034	0.037	0.024	0.025	0.037	0.036	0.033	0.037	0.024	0.013	0.028	0.026	0.012	0.027	0.012
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006	0.006	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0042	0.0041	0.0042	0.0042	0.0047	0.0050	0.0042	0.0042	0.0042	0.0042	0.0047	0.0050	0.0042	0.0042	0.0043	0.0042	0.0047	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.038	0.035	0.035	0.038	0.006	0.006	0.038	0.031	0.033	0.038	0.006	0.006	0.038	0.031	0.029	0.038	0.006	0.008	0.039	0.033	0.007	0.039	0.007
Cobalt (Co)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.002	0.001	0.001	0.002	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.0	0.9	1.0	1.0	1.1	1.1	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.0	1.0	1.0	1.1	1.4	1.2	1.2	1.3	1.2	1.3
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.041	0.041	0.042	0.042	0.047	0.050	0.041	0.041	0.042	0.042	0.047	0.050	0.041	0.041	0.042	0.042	0.047	0.005	0.005	0.005	0.006	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.06	0.05	0.05	0.06	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0021	0.0019	0.0005	0.0020	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0045	0.0045	0.0045	0.0046	0.0047	0.0050	0.0045	0.0045	0.0045	0.0046	0.0047	0.0050	0.0045	0.0045	0.0045	0.0046	0.0047	0.0001	0.0006	0.0006	0.0002	0.0006	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	7	7	8	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.006	0.006	0.005	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.084	0.083	0.084	0.084	0.095	0.100	0.084	0.084	0.085	0.084	0.095	0.100	0.084	0.084	0.086	0.084	0.095	0.002	0.005	0.005	0.005	0.005	0.002
Vanadium (V)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.012	0.012	0.012	0.012	0.013	0.014	0.012	0.012	0.012	0.012	0.013	0.014	0.012	0.012	0.012	0.012	0.013	0.003	0.003	0.003	0.002	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-5 Water Quality Results From Mine Area 1,000 m Downstream of Clarification Pond Outlets (continued)

Antsahalava River 1,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	33	30	33	32	44	45	33	30	33	32	44	45	33	30	33	32	44	45	33	30	33	32	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.03	0.04	0.03	0.05	0.05	0.04	0.03	0.04	0.03	0.05	0.05	0.04	0.03	0.04	0.03	0.05	0.05	0.04	0.03	0.04	0.03	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	2.6	2.3	2.3	2.3	2.3	2.6	2.6	2.3	2.3	2.3	2.3	2.6	2.6	2.3	2.3	2.3	2.3	2.6	2.6	2.3	2.3	2.3	2.3	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05
Magnesium (Mg)	mg/L	-	-	8	6	5	6	6	8	8	6	5	6	6	8	8	6	5	6	6	8	8	6	5	6	6	8
Potassium (K)	mg/L	-	-	0.8	0.6	0.5	0.6	0.5	0.8	0.8	0.6	0.5	0.6	0.5	0.8	0.8	0.6	0.5	0.6	0.5	0.8	0.8	0.6	0.5	0.6	0.5	0.8
Sodium (Na)	mg/L	-	-	2.8	2.9	3.0	2.9	2.9	2.7	2.8	2.9	3.0	2.9	2.9	2.7	2.8	2.9	3.0	2.9	2.9	2.7	2.8	2.9	3.0	2.9	2.9	2.7
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0025	0.0029	0.0026	0.0027	0.0003	0.0003	0.0025	0.0029	0.0026	0.0027	0.0003	0.0003	0.0025	0.0029	0.0026	0.0027	0.0003	0.0003	0.0025	0.0029	0.0026	0.0027	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0013	0.0017	0.0013	0.0014	0.0002	0.0002	0.0013	0.0017	0.0013	0.0014	0.0002	0.0002	0.0013	0.0017	0.0013	0.0014	0.0002	0.0002	0.0013	0.0017	0.0013	0.0014	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.067	0.091	0.069	0.077	0.013	0.013	0.067	0.091	0.069	0.077	0.013	0.013	0.067	0.091	0.069	0.077	0.013	0.013	0.067	0.091	0.069	0.077	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.021	0.022	0.021	0.021	0.008	0.008	0.021	0.022	0.021	0.021	0.008	0.008	0.021	0.022	0.021	0.021	0.008	0.008	0.021	0.022	0.021	0.021	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.003	0.004	0.003	0.005	0.005	0.004	0.003	0.004	0.003	0.005	0.005	0.004	0.003	0.004	0.003	0.005	0.005	0.004	0.003	0.004	0.003	0.005
Iron (Fe)	mg/L	-	-	1.4	1.0	0.9	1.0	1.0	1.4	1.4	1.0	0.9	1.0	1.0	1.4	1.4	1.0	0.9	1.0	1.0	1.4	1.4	1.0	0.9	1.0	1.0	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.04	0.05	0.05	0.06	0.06	0.05	0.04	0.05	0.05	0.06	0.06	0.05	0.04	0.05	0.05	0.06	0.06	0.05	0.04	0.05	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0046	0.0062	0.0047	0.0052	0.0005	0.0005	0.0046	0.0062	0.0047	0.0052	0.0005	0.0005	0.0046	0.0062	0.0047	0.0052	0.0005	0.0005	0.0046	0.0062	0.0047	0.0052	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0012	0.0016	0.0013	0.0014	0.0001	0.0001	0.0012	0.0016	0.0013	0.0014	0.0001	0.0001	0.0012	0.0016	0.0013	0.0014	0.0001	0.0001	0.0012	0.0016	0.0013	0.0014	0.0001
Silicon (Si)	mg/L	-	-	9	7	6	7	6	9	9	7	6	7	6	9	9	7	6	7	6	9	9	7	6	7	6	9
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.007	0.006	0.007	0.004	0.005	0.006	0.007	0.006	0.007	0.004	0.005	0.006	0.007	0.006	0.007	0.004	0.005	0.006	0.007	0.006	0.007	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.006	0.007	0.006	0.006	0.002	0.002	0.006	0.007	0.006	0.006	0.002	0.002	0.006	0.007	0.006	0.006	0.002	0.002	0.006	0.007	0.006	0.006	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.005	0.006	0.005	0.005	0.002	0.003	0.005	0.006	0.005	0.005	0.002	0.003	0.005	0.006	0.005	0.005	0.002	0.003	0.005	0.006	0.005	0.005	0.002

Notes

1 World Health Organization (WHO) 2004 Guidelines for drinking water quæ Notes

2 Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3 Based on the un-ionized portion of ammonia.

4 Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5 Based on long-term exposure.

6 Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7 Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8 Based on an alkalinity value of less than 60 mg/L.

9 Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10 Based on the dissolved form of this metal.

11 Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12 Based on a dissolved saturation of at least 80%.

13 Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-5 Water Quality Results From Mine Area 1,000 m Downstream of Clarification Pond Outlets (continued)

Sahaviara River 1,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	33	33	29	32	44	45	33	33	29	32	44	45	33	33	29	32	44	45	33	33	29	32	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.03	0.04	0.05	0.05	0.04	0.04	0.03	0.04	0.05	0.05	0.04	0.04	0.03	0.04	0.05	0.05	0.04	0.04	0.03	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.6	1.5	1.6	1.6	1.5	1.5	1.6	1.5	1.6	1.6	1.5	1.5	1.6	1.5	1.6	1.6	1.5	1.5	1.6	1.5	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	2.6	2.2	2.2	2.2	2.2	2.6	2.6	2.2	2.2	2.2	2.2	2.6	2.6	2.2	2.2	2.2	2.2	2.6	2.6	2.2	2.2	2.2	2.2	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	6	6	5	6	8	8	6	6	5	6	8	8	6	6	5	6	8	8	6	6	5	6	8
Potassium (K)	mg/L	-	-	0.8	0.6	0.6	0.5	0.5	0.7	0.8	0.6	0.6	0.5	0.5	0.7	0.8	0.6	0.6	0.5	0.5	0.7	0.8	0.6	0.6	0.5	0.5	0.7
Sodium (Na)	mg/L	-	-	2.8	2.6	2.6	2.8	2.7	2.7	2.8	2.6	2.6	2.8	2.7	2.7	2.8	2.6	2.6	2.8	2.7	2.7	2.8	2.6	2.6	2.8	2.7	2.7
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0018	0.0016	0.0020	0.0017	0.0003	0.0003	0.0018	0.0016	0.0020	0.0017	0.0003	0.0003	0.0018	0.0016	0.0020	0.0017	0.0003	0.0003	0.0018	0.0016	0.0020	0.0017	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0009	0.0009	0.0014	0.0011	0.0002	0.0002	0.0009	0.0009	0.0014	0.0011	0.0002	0.0002	0.0009	0.0009	0.0014	0.0011	0.0002	0.0002	0.0009	0.0009	0.0014	0.0011	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.048	0.047	0.079	0.062	0.013	0.013	0.048	0.047	0.079	0.062	0.013	0.013	0.048	0.047	0.079	0.062	0.013	0.013	0.048	0.047	0.079	0.062	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.014	0.014	0.016	0.015	0.008	0.008	0.014	0.014	0.016	0.015	0.008	0.008	0.014	0.014	0.016	0.015	0.008	0.008	0.014	0.014	0.016	0.015	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.003	0.003	0.005	0.005	0.004	0.004	0.003	0.003	0.005	0.005	0.004	0.004	0.003	0.003	0.005	0.005	0.004	0.004	0.003	0.003	0.005
Iron (Fe)	mg/L	-	-	1.4	1.0	1.0	0.9	1.0	1.4	1.4	1.0	1.0	0.9	1.0	1.4	1.4	1.0	1.0	0.9	1.0	1.4	1.4	1.0	1.0	0.9	1.0	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.04	0.05	0.06	0.06	0.05	0.05	0.04	0.05	0.06	0.06	0.05	0.05	0.04	0.05	0.06	0.06	0.05	0.05	0.04	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0031	0.0031	0.0052	0.0040	0.0005	0.0005	0.0031	0.0031	0.0052	0.0040	0.0005	0.0005	0.0031	0.0031	0.0052	0.0040	0.0005	0.0005	0.0031	0.0031	0.0052	0.0040	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0008	0.0008	0.0013	0.0010	0.0001	0.0001	0.0008	0.0008	0.0013	0.0010	0.0001	0.0001	0.0008	0.0008	0.0013	0.0010	0.0001	0.0001	0.0008	0.0008	0.0013	0.0010	0.0001
Silicon (Si)	mg/L	-	-	9	7	7	6	6	9	9	7	7	6	6	9	9	7	7	6	6	9	9	7	7	6	6	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.006	0.005	0.004	0.005	0.005	0.005	0.006	0.005	0.004	0.005	0.005	0.005	0.006	0.005	0.004	0.005	0.005	0.005	0.006	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.005	0.004	0.005	0.004	0.002	0.002	0.005	0.004	0.005	0.004	0.002	0.002	0.005	0.004	0.005	0.004	0.002	0.002	0.005	0.004	0.005	0.004	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.004	0.004	0.005	0.004	0.002	0.003	0.004	0.004	0.005	0.004	0.002	0.003	0.004	0.004	0.005	0.004	0.002	0.003	0.004	0.004	0.005	0.004	0.002

Notes

1 World Health Organization (WHO) Notes

2 Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3 Based on the un-ionized portion of ammonia.

4 Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5 Based on long-term exposure.

6 Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7 Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8 Based on an alkalinity value of less than 60 mg/L.

9 Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10 Based on the dissolved form of this metal.

11 Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12 Based on a dissolved saturation of at least 80%.

13 Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-5 Water Quality Results From Mine Area 1,000 m Downstream of Clarification Pond Outlets (continued)

Sahamarirana River 1,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	29	29	33	33	41	45	29	29	33	33	41	45	29	29	33	33	41	45	29	29	33	33	41
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.03	0.03	0.04	0.04	0.05	0.05	0.03	0.03	0.04	0.04	0.05	0.05	0.03	0.03	0.04	0.04	0.05	0.05	0.03	0.03	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.4	1.4	1.4	1.4	1.5	1.6	1.4	1.4	1.4	1.4	1.5	1.6	1.4	1.4	1.4	1.4	1.5	1.6	1.4	1.4	1.4	1.4	1.5
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	2.6	2.0	2.1	2.1	2.1	2.4	2.6	2.0	2.1	2.1	2.1	2.4	2.6	2.0	2.1	2.1	2.1	2.4	2.6	2.0	2.1	2.1	2.1	2.4
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05
Magnesium (Mg)	mg/L	-	-	8	6	6	6	6	8	8	6	6	6	6	8	8	6	6	6	6	8	8	6	6	6	6	8
Potassium (K)	mg/L	-	-	0.8	0.5	0.5	0.6	0.6	0.7	0.8	0.5	0.5	0.6	0.6	0.7	0.8	0.5	0.5	0.6	0.6	0.7	0.8	0.5	0.5	0.6	0.6	0.7
Sodium (Na)	mg/L	-	-	2.8	2.5	2.5	2.3	2.4	2.5	2.8	2.5	2.5	2.3	2.4	2.5	2.8	2.5	2.5	2.3	2.4	2.5	2.8	2.5	2.5	2.3	2.4	2.5
Sulphate (SO ₄)	mg/L	-	-	1	2	2	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0023	0.0023	0.0018	0.0018	0.0003	0.0003	0.0023	0.0023	0.0018	0.0018	0.0003	0.0003	0.0023	0.0023	0.0018	0.0018	0.0003	0.0003	0.0023	0.0023	0.0018	0.0018	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0010	0.0011	0.0006	0.0006	0.0001	0.0002	0.0010	0.0011	0.0006	0.0006	0.0001	0.0002	0.0010	0.0011	0.0006	0.0006	0.0001	0.0002	0.0010	0.0011	0.0006	0.0006	0.0001
Barium (Ba)	mg/L	0.7	-	0.013	0.051	0.054	0.030	0.033	0.012	0.013	0.051	0.054	0.030	0.033	0.012	0.013	0.051	0.054	0.030	0.033	0.012	0.013	0.051	0.054	0.030	0.033	0.012
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.023	0.022	0.012	0.010	0.007	0.008	0.023	0.022	0.012	0.010	0.007	0.008	0.023	0.022	0.012	0.010	0.007	0.008	0.023	0.022	0.012	0.010	0.007
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.003	0.003	0.004	0.004	0.004	0.005	0.003	0.003	0.004	0.004	0.004	0.005	0.003	0.003	0.004	0.004	0.004	0.005	0.003	0.003	0.004	0.004	0.004
Iron (Fe)	mg/L	-	-	1.4	0.9	0.9	1.1	1.0	1.3	1.4	0.9	0.9	1.1	1.0	1.3	1.4	0.9	0.9	1.1	1.0	1.3	1.4	0.9	0.9	1.1	1.0	1.3
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.04	0.04	0.05	0.05	0.06	0.06	0.04	0.04	0.05	0.05	0.06	0.06	0.04	0.04	0.05	0.05	0.06	0.06	0.04	0.04	0.05	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0037	0.0038	0.0019	0.0020	0.0005	0.0005	0.0037	0.0038	0.0019	0.0020	0.0005	0.0005	0.0037	0.0038	0.0019	0.0020	0.0005	0.0005	0.0037	0.0038	0.0019	0.0020	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.005	0.005	0.006	0.006	0.007	0.008	0.005	0.005	0.006	0.006	0.007	0.008	0.005	0.005	0.006	0.006	0.007	0.008	0.005	0.005	0.006	0.006	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0010	0.0010	0.0005	0.0006	0.0001	0.0001	0.0010	0.0010	0.0005	0.0006	0.0001	0.0001	0.0010	0.0010	0.0005	0.0006	0.0001	0.0001	0.0010	0.0010	0.0005	0.0006	0.0001
Silicon (Si)	mg/L	-	-	9	6	6	7	7	8	9	6	6	7	7	8	9	6	6	7	7	8	9	6	6	7	7	8
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.006	0.005	0.005	0.004	0.005	0.006	0.006	0.005	0.005	0.004	0.005	0.006	0.006	0.005	0.005	0.004	0.005	0.006	0.006	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.005	0.005	0.005	0.005	0.002	0.002	0.005	0.005	0.005	0.005	0.002	0.002	0.005	0.005	0.005	0.005	0.002	0.002	0.005	0.005	0.005	0.005	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.004	0.004	0.003	0.003	0.002	0.003	0.004	0.004	0.003	0.003	0.002	0.003	0.004	0.004	0.003	0.003	0.002	0.003	0.004	0.004	0.003	0.003	0.002

Notes

1 World Health Organization (WHO) 2004 Guidelines for drinking water quæ Notes

2 Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3 Based on the un-ionized portion of ammonia.

4 Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5 Based on long-term exposure.

6 Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7 Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8 Based on an alkalinity value of less than 60 mg/L.

9 Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10 Based on the dissolved form of this metal.

11 Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12 Based on a dissolved saturation of at least 80%.

13 Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-5 Water Quality Results From Mine Area 1,000 m Downstream of Clarification Pond Outlets (continued)

Torotorofotsy River 1,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	40	42	41	44	45	45	40	42	41	44	45	45	40	42	41	44	45	45	40	42	41	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.5	2.5	2.5	2.6	2.6	2.6	2.5	2.5	2.5	2.6	2.6	2.6	2.5	2.5	2.5	2.6	2.6	2.6	2.5	2.5	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	2.8	2.8	2.6	2.6	2.6	2.7	2.8	2.8	2.6	2.6	2.6	2.7	2.8	2.8	2.6	2.6	2.6	2.7	2.8	2.8	2.6	2.6	2.6	2.7
Sulphate (SO ₄)	mg/L	-	-	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0016	0.0014	0.0014	0.0003	0.0003	0.0003	0.0016	0.0014	0.0014	0.0003	0.0003	0.0003	0.0016	0.0014	0.0014	0.0003	0.0003	0.0003	0.0016	0.0014	0.0014	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0006	0.0003	0.0005	0.0002	0.0002	0.0002	0.0006	0.0003	0.0005	0.0002	0.0002	0.0002	0.0006	0.0003	0.0005	0.0002	0.0002	0.0002	0.0006	0.0003	0.0005	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.026	0.014	0.023	0.013	0.013	0.013	0.026	0.014	0.023	0.013	0.013	0.013	0.026	0.014	0.023	0.013	0.013	0.013	0.026	0.014	0.023	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.031	0.010	0.029	0.008	0.008	0.008	0.031	0.010	0.029	0.008	0.008	0.008	0.031	0.010	0.029	0.008	0.008	0.008	0.031	0.010	0.029	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.3	1.3	1.3	1.4	1.4	1.4	1.3	1.3	1.3	1.4	1.4	1.4	1.3	1.3	1.3	1.4	1.4	1.4	1.3	1.3	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0018	0.0006	0.0015	0.0005	0.0005	0.0005	0.0018	0.0006	0.0015	0.0005	0.0005	0.0005	0.0018	0.0006	0.0015	0.0005	0.0005	0.0005	0.0018	0.0006	0.0015	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0005	0.0002	0.0004	0.0001	0.0001	0.0001	0.0005	0.0002	0.0004	0.0001	0.0001	0.0001	0.0005	0.0002	0.0004	0.0001	0.0001	0.0001	0.0005	0.0002	0.0004	0.0001
Silicon (Si)	mg/L	-	-	9	9	8	9	8	9	9	9	8	9	8	9	9	9	8	9	8	9	9	9	8	9	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.006	0.005	0.005	0.004	0.005	0.005	0.006	0.005	0.005	0.004	0.005	0.005	0.006	0.005	0.005	0.004	0.005	0.005	0.006	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.004	0.004	0.004	0.002	0.002	0.002	0.004	0.004	0.004	0.002	0.002	0.002	0.004	0.004	0.004	0.002	0.002	0.002	0.004	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1 World Health Organization (WI)Notes

2 Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3 Based on the un-ionized portion of ammonia.

4 Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5 Based on long-term exposure.

6 Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7 Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8 Based on an alkalinity value of less than 60 mg/L.

9 Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10 Based on the dissolved form of this metal.

11 Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12 Based on a dissolved saturation of at least 80%.

13 Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-5 Water Quality Results From Mine Area 1,000 m Downstream of Clarification Pond Outlets (continued)

Sakalava River 1,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	41	37	41	44	45	45	41	37	41	44	45	45	41	37	41	44	45	45	41	37	41	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.5	2.4	2.4	2.6	2.6	2.6	2.5	2.4	2.4	2.6	2.6	2.6	2.5	2.4	2.4	2.6	2.6	2.6	2.5	2.4	2.4	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	7	8	8	8	8	8	7	8	8	8	8	8	7	8	8	8	8	8	7	8	8
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7
Sodium (Na)	mg/L	-	-	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7
Sulphate (SO ₄)	mg/L	-	-	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0021	0.0020	0.0017	0.0003	0.0003	0.0003	0.0021	0.0020	0.0017	0.0003	0.0003	0.0003	0.0021	0.0020	0.0017	0.0003	0.0003	0.0003	0.0021	0.0020	0.0017	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0003	0.0007	0.0003	0.0002	0.0002	0.0002	0.0003	0.0007	0.0003	0.0002	0.0002	0.0002	0.0003	0.0007	0.0003	0.0002	0.0002	0.0002	0.0003	0.0007	0.0003	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.013	0.030	0.013	0.013	0.013	0.013	0.013	0.030	0.013	0.013	0.013	0.013	0.013	0.030	0.013	0.013	0.013	0.013	0.013	0.030	0.013	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.008	0.046	0.009	0.008	0.008	0.008	0.008	0.046	0.009	0.008	0.008	0.008	0.008	0.046	0.009	0.008	0.008	0.008	0.008	0.046	0.009	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0005	0.0024	0.0005	0.0005	0.0005	0.0005	0.0005	0.0024	0.0005	0.0005	0.0005	0.0005	0.0005	0.0024	0.0005	0.0005	0.0005	0.0005	0.0005	0.0024	0.0005	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0003	0.0007	0.0002	0.0001	0.0001	0.0001	0.0003	0.0007	0.0002	0.0001	0.0001	0.0001	0.0003	0.0007	0.0002	0.0001	0.0001	0.0001	0.0003	0.0007	0.0002	0.0001
Silicon (Si)	mg/L	-	-	9	9	8	8	8	9	9	9	8	8	8	9	9	9	8	8	8	9	9	9	8	8	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.006	0.006	0.005	0.004	0.005	0.005	0.006	0.006	0.005	0.004	0.005	0.005	0.006	0.006	0.005	0.004	0.005	0.005	0.006	0.006	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.005	0.005	0.005	0.002	0.002	0.002	0.005	0.005	0.005	0.002	0.002	0.002	0.005	0.005	0.005	0.002	0.002	0.002	0.005	0.005	0.005	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water qu

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-5 Water Quality Results From Mine Area 1,000 m Downstream of Clarification Pond Outlets (continued)

Ankaja River 1,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	37	37	40	37	42	45	37	37	40	37	42	45	37	37	40	37	42	45	37	37	40	37	42
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.4	1.5	1.5	1.6	1.5	1.5	1.4	1.5	1.5	1.6	1.5	1.5	1.4	1.5	1.5	1.6	1.5	1.5	1.4	1.5	1.5
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.3	2.3	2.4	2.4	2.5	2.6	2.3	2.3	2.4	2.4	2.5	2.6	2.3	2.3	2.4	2.4	2.5	2.6	2.3	2.3	2.4	2.4	2.5
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	7	7	7	8	8	7	7	7	7	8	8	7	7	7	7	8	8	7	7	7	7	8
Potassium (K)	mg/L	-	-	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7
Sodium (Na)	mg/L	-	-	2.8	2.4	2.4	2.4	2.4	2.6	2.8	2.4	2.4	2.4	2.4	2.6	2.8	2.4	2.4	2.4	2.4	2.6	2.8	2.4	2.4	2.4	2.4	2.6
Sulphate (SO ₄)	mg/L	-	-	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0019	0.0020	0.0018	0.0021	0.0003	0.0003	0.0019	0.0020	0.0018	0.0021	0.0003	0.0003	0.0019	0.0020	0.0018	0.0021	0.0003	0.0003	0.0019	0.0020	0.0018	0.0021	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0007	0.0006	0.0003	0.0007	0.0002	0.0002	0.0007	0.0006	0.0003	0.0007	0.0002	0.0002	0.0007	0.0006	0.0003	0.0007	0.0002	0.0002	0.0007	0.0006	0.0003	0.0007	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.028	0.026	0.012	0.027	0.012	0.013	0.028	0.026	0.012	0.027	0.012	0.013	0.028	0.026	0.012	0.027	0.012	0.013	0.028	0.026	0.012	0.027	0.012
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.039	0.033	0.007	0.039	0.007	0.008	0.039	0.033	0.007	0.039	0.007	0.008	0.039	0.033	0.007	0.039	0.007	0.008	0.039	0.033	0.007	0.039	0.007
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.2	1.2	1.3	1.2	1.3	1.4	1.2	1.2	1.3	1.2	1.3	1.4	1.2	1.2	1.3	1.2	1.3	1.4	1.2	1.2	1.3	1.2	1.3
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.06	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0021	0.0019	0.0005	0.0020	0.0005	0.0005	0.0021	0.0019	0.0005	0.0020	0.0005	0.0005	0.0021	0.0019	0.0005	0.0020	0.0005	0.0005	0.0021	0.0019	0.0005	0.0020	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0006	0.0006	0.0002	0.0006	0.0001	0.0001	0.0006	0.0006	0.0002	0.0006	0.0001	0.0001	0.0006	0.0006	0.0002	0.0006	0.0001	0.0001	0.0006	0.0006	0.0002	0.0006	0.0001
Silicon (Si)	mg/L	-	-	9	7	7	8	8	9	9	7	7	8	8	9	9	7	7	8	8	9	9	7	7	8	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.006	0.005	0.006	0.004	0.005	0.006	0.006	0.005	0.006	0.004	0.005	0.006	0.006	0.005	0.006	0.004	0.005	0.006	0.006	0.005	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.005	0.005	0.005	0.005	0.002	0.002	0.005	0.005	0.005	0.005	0.002	0.002	0.005	0.005	0.005	0.005	0.002	0.002	0.005	0.005	0.005	0.005	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-5 Water Quality Results From Mine Area 1,000 m Downstream of Clarification Pond Outlets (continued)

Antsahalava River 1,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	33	30	33	32	44	45	33	30	33	32	44	45	33	30	33	32	44	33	25	22	24	23	33
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.03	0.04	0.03	0.05	0.05	0.04	0.03	0.04	0.03	0.05	0.05	0.04	0.03	0.04	0.03	0.05	0.18	0.12	0.11	0.12	0.11	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.4	1.4	1.5	1.5	1.5	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.04	0.04	0.04	0.04	0.05
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.3	2.3	2.3	2.3	2.6	2.6	2.3	2.3	2.3	2.3	2.6	2.6	2.3	2.3	2.3	2.3	2.6	3.2	2.7	2.6	2.7	2.7	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05
Magnesium (Mg)	mg/L	-	-	8	6	5	6	6	8	8	6	5	6	6	8	8	6	5	6	6	8	7	5	5	5	5	7
Potassium (K)	mg/L	-	-	0.8	0.6	0.5	0.6	0.5	0.8	0.8	0.6	0.5	0.6	0.5	0.8	0.8	0.6	0.5	0.6	0.5	0.8	0.9	0.7	0.6	0.7	0.6	0.9
Sodium (Na)	mg/L	-	-	2.8	2.9	3.0	2.9	2.9	2.7	2.8	2.9	3.0	2.9	2.9	2.7	2.8	2.9	3.0	2.9	2.9	2.7	1.3	1.8	2.1	1.9	2.0	1.3
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	2	2	3	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0025	0.0029	0.0026	0.0027	0.0003	0.0003	0.0025	0.0029	0.0026	0.0027	0.0003	0.0003	0.0025	0.0029	0.0026	0.0027	0.0003	0.0500	0.0372	0.0333	0.0367	0.0350	0.0496
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0013	0.0017	0.0013	0.0014	0.0002	0.0002	0.0013	0.0017	0.0013	0.0014	0.0002	0.0002	0.0013	0.0017	0.0013	0.0014	0.0002	0.0055	0.0050	0.0049	0.0050	0.0049	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.067	0.091	0.069	0.077	0.013	0.013	0.067	0.091	0.069	0.077	0.013	0.013	0.067	0.091	0.069	0.077	0.013	0.025	0.075	0.100	0.079	0.089	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.007	0.006	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0050	0.0037	0.0033	0.0037	0.0035	0.0050
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.021	0.022	0.021	0.021	0.008	0.008	0.021	0.022	0.021	0.021	0.008	0.008	0.021	0.022	0.021	0.021	0.008	0.006	0.020	0.022	0.020	0.021	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.005	0.004	0.003	0.004	0.003	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.003	0.004	0.003	0.005	0.005	0.004	0.003	0.004	0.003	0.005	0.005	0.004	0.003	0.004	0.003	0.005	0.005	0.004	0.003	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.0	0.9	1.0	1.0	1.4	1.4	1.0	0.9	1.0	1.0	1.4	1.4	1.0	0.9	1.0	1.0	1.4	1.1	0.8	0.7	0.8	0.8	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.050	0.036	0.032	0.036	0.034	0.050
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.04	0.05	0.05	0.06	0.06	0.05	0.04	0.05	0.05	0.06	0.06	0.05	0.04	0.05	0.05	0.06	0.07	0.05	0.05	0.05	0.05	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002	0.0005	0.0004	0.0003	0.0004	0.0004	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0046	0.0062	0.0047	0.0052	0.0005	0.0005	0.0046	0.0062	0.0047	0.0052	0.0005	0.0005	0.0046	0.0062	0.0047	0.0052	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0012	0.0016	0.0013	0.0014	0.0001	0.0001	0.0012	0.0016	0.0013	0.0014	0.0001	0.0001	0.0012	0.0016	0.0013	0.0014	0.0001	0.0050	0.0047	0.0047	0.0047	0.0047	0.0050
Silicon (Si)	mg/L	-	-	9	7	6	7	6	9	9	7	6	7	6	9	9	7	6	7	6	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.007	0.006	0.007	0.004	0.005	0.006	0.007	0.006	0.007	0.004	0.005	0.006	0.007	0.006	0.007	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.006	0.007	0.006	0.006	0.002	0.002	0.006	0.007	0.006	0.006	0.002	0.002	0.006	0.007	0.006	0.006	0.002	0.100	0.074	0.067	0.073	0.070	0.099
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.004	0.003	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.005	0.006	0.005	0.005	0.002	0.003	0.005	0.006	0.005	0.005	0.002	0.003	0.005	0.006	0.005	0.005	0.002	0.014	0.013	0.013	0.013	0.012	0.014

Notes

1 World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2 Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3 Based on the un-ionized portion of ammonia.

4 Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5 Based on long-term exposure.

6 Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7 Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8 Based on an alkalinity value of less than 60 mg/L.

9 Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10 Based on the dissolved form of this metal.

11 Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12 Based on a dissolved saturation of at least 80%.

13 Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-5 Water Quality Results From Mine Area 1,000 m Downstream of Clarification Pond Outlets (continued)

Sahaviara River 1,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closur	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closur	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closur	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	33	33	29	32	44	45	33	33	29	32	44	45	33	33	29	31	44	33	25	24	21	22	32
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.03	0.04	0.05	0.05	0.04	0.04	0.03	0.04	0.05	0.05	0.04	0.04	0.03	0.03	0.05	0.18	0.13	0.12	0.11	0.11	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.6	1.5	1.6	1.6	1.5	1.5	1.6	1.5	1.6	1.6	1.5	1.5	1.6	1.5	1.6	1.4	1.3	1.3	1.4	1.4	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.04	0.04	0.04	0.04	0.05
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.2	2.2	2.2	2.2	2.6	2.6	2.2	2.2	2.2	2.2	2.6	2.6	2.2	2.2	2.2	2.2	2.6	3.2	2.6	2.6	2.5	2.5	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	6	6	5	6	8	8	6	6	5	6	8	8	6	6	5	6	8	7	5	5	4	5	7
Potassium (K)	mg/L	-	-	0.8	0.6	0.6	0.5	0.5	0.7	0.8	0.6	0.6	0.5	0.5	0.7	0.8	0.6	0.6	0.5	0.5	0.7	0.9	0.7	0.7	0.6	0.6	0.9
Sodium (Na)	mg/L	-	-	2.8	2.6	2.6	2.8	2.7	2.7	2.8	2.6	2.6	2.8	2.7	2.7	2.8	2.6	2.6	2.8	2.7	2.7	1.3	1.5	1.6	1.9	1.8	1.3
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	2	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0018	0.0016	0.0020	0.0017	0.0003	0.0003	0.0018	0.0016	0.0020	0.0017	0.0003	0.0003	0.0018	0.0016	0.0020	0.0018	0.0003	0.0500	0.0375	0.0369	0.0317	0.0339	0.0491
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0009	0.0009	0.0014	0.0011	0.0002	0.0002	0.0009	0.0009	0.0014	0.0011	0.0002	0.0002	0.0009	0.0009	0.0014	0.0011	0.0002	0.0055	0.0047	0.0046	0.0046	0.0046	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.048	0.047	0.079	0.062	0.013	0.013	0.048	0.047	0.079	0.062	0.013	0.013	0.048	0.047	0.079	0.064	0.013	0.025	0.057	0.058	0.091	0.076	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.006	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0038	0.0037	0.0032	0.0034	0.0049
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.014	0.014	0.016	0.015	0.008	0.008	0.014	0.014	0.016	0.015	0.008	0.008	0.014	0.014	0.016	0.015	0.008	0.006	0.013	0.013	0.015	0.015	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.005	0.004	0.004	0.003	0.003	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.003	0.003	0.005	0.005	0.004	0.004	0.003	0.003	0.005	0.005	0.004	0.004	0.003	0.003	0.005	0.005	0.004	0.004	0.003	0.003	0.005
Iron (Fe)	mg/L	-	-	1.4	1.0	1.0	0.9	1.0	1.4	1.4	1.0	1.0	0.9	1.0	1.4	1.4	1.0	1.0	0.9	1.0	1.4	1.1	0.8	0.8	0.7	0.8	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.050	0.037	0.036	0.030	0.033	0.049
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.04	0.05	0.06	0.06	0.05	0.05	0.04	0.05	0.06	0.06	0.05	0.05	0.04	0.05	0.06	0.07	0.05	0.05	0.05	0.05	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0005	0.0004	0.0004	0.0003	0.0003	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0031	0.0031	0.0052	0.0040	0.0005	0.0005	0.0031	0.0031	0.0052	0.0040	0.0005	0.0005	0.0031	0.0031	0.0052	0.0042	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.005	0.006	0.008	0.008	0.006	0.006	0.005	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0008	0.0008	0.0013	0.0010	0.0001	0.0001	0.0008	0.0008	0.0013	0.0010	0.0001	0.0001	0.0008	0.0008	0.0013	0.0011	0.0001	0.0050	0.0044	0.0043	0.0044	0.0043	0.0049
Silicon (Si)	mg/L	-	-	9	7	7	6	6	9	9	7	7	6	6	9	9	7	7	6	6	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.006	0.005	0.004	0.005	0.005	0.005	0.006	0.005	0.004	0.005	0.005	0.005	0.006	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.005	0.004	0.005	0.004	0.002	0.002	0.005	0.004	0.005	0.004	0.002	0.002	0.005	0.004	0.005	0.004	0.002	0.100	0.075	0.074	0.063	0.068	0.098
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.004	0.004	0.003	0.003	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.004	0.004	0.005	0.004	0.002	0.003	0.004	0.004	0.005	0.004	0.002	0.003	0.004	0.004	0.005	0.004	0.002	0.014	0.012	0.012	0.012	0.012	0.013

Notes

1 World Health Organization (WHO) 2004 Guidelines for drinking water qualit Notes

2 Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3 Based on the un-ionized portion of ammonia.

4 Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5 Based on long-term exposure.

6 Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7 Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8 Based on an alkalinity value of less than 60 mg/L.

9 Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10 Based on the dissolved form of this metal.

11 Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12 Based on a dissolved saturation of at least 80%.

13 Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-5 Water Quality Results From Mine Area 1,000 m Downstream of Clarification Pond Outlets (continued)

Sahamarirana River 1,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	29	29	33	33	41	45	29	29	33	33	41	45	29	29	33	33	41	33	22	22	25	24	30
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.03	0.03	0.04	0.04	0.05	0.05	0.03	0.03	0.04	0.04	0.05	0.05	0.03	0.03	0.04	0.04	0.05	0.18	0.11	0.11	0.13	0.12	0.16
Nitrate (NO ₃)	mg/L	50	-	1.6	1.4	1.4	1.4	1.4	1.5	1.6	1.4	1.4	1.4	1.4	1.5	1.6	1.4	1.4	1.4	1.4	1.5	1.4	1.2	1.3	1.2	1.2	1.3
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.05	0.04	0.04	0.04	0.04	0.05
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.0	2.1	2.1	2.1	2.4	2.6	2.0	2.1	2.1	2.1	2.4	2.6	2.0	2.1	2.1	2.1	2.4	3.2	2.4	2.4	2.5	2.5	3.0
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05
Magnesium (Mg)	mg/L	-	-	8	6	6	6	6	8	8	6	6	6	6	8	8	6	6	6	6	8	7	5	5	5	5	6
Potassium (K)	mg/L	-	-	0.8	0.5	0.5	0.6	0.6	0.7	0.8	0.5	0.5	0.6	0.6	0.7	0.8	0.5	0.5	0.6	0.6	0.7	0.9	0.6	0.6	0.7	0.6	0.8
Sodium (Na)	mg/L	-	-	2.8	2.5	2.5	2.3	2.4	2.5	2.8	2.5	2.5	2.3	2.4	2.5	2.8	2.5	2.5	2.3	2.4	2.5	1.3	1.5	1.6	1.3	1.3	1.2
Sulphate (SO ₄)	mg/L	-	-	1	2	2	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1	2	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0023	0.0023	0.0018	0.0018	0.0003	0.0003	0.0023	0.0023	0.0018	0.0018	0.0003	0.0003	0.0023	0.0023	0.0018	0.0018	0.0003	0.0500	0.0331	0.0328	0.0374	0.0359	0.0461
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0010	0.0011	0.0006	0.0006	0.0001	0.0002	0.0010	0.0011	0.0006	0.0006	0.0001	0.0002	0.0010	0.0011	0.0006	0.0006	0.0001	0.0055	0.0043	0.0043	0.0044	0.0043	0.0050
Barium (Ba)	mg/L	0.7	-	0.013	0.051	0.054	0.030	0.033	0.012	0.013	0.051	0.054	0.030	0.033	0.012	0.013	0.051	0.054	0.030	0.033	0.012	0.025	0.059	0.062	0.039	0.043	0.023
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.005	0.005	0.005	0.005	0.006
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0033	0.0033	0.0037	0.0036	0.0046
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.023	0.022	0.012	0.010	0.007	0.008	0.023	0.022	0.012	0.010	0.007	0.008	0.023	0.022	0.012	0.010	0.007	0.006	0.022	0.022	0.011	0.009	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.005	0.003	0.003	0.004	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.003	0.003	0.004	0.004	0.004	0.005	0.003	0.003	0.004	0.004	0.004	0.005	0.003	0.003	0.004	0.004	0.004	0.005	0.003	0.003	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	0.9	0.9	1.1	1.0	1.3	1.4	0.9	0.9	1.1	1.0	1.3	1.4	0.9	0.9	1.1	1.0	1.3	1.1	0.7	0.7	0.9	0.8	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.050	0.032	0.032	0.037	0.036	0.046
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.04	0.04	0.05	0.05	0.06	0.06	0.04	0.04	0.05	0.05	0.06	0.06	0.04	0.04	0.05	0.05	0.06	0.07	0.05	0.05	0.05	0.05	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0005	0.0003	0.0003	0.0004	0.0004	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0037	0.0038	0.0019	0.0020	0.0005	0.0005	0.0037	0.0038	0.0019	0.0020	0.0005	0.0005	0.0037	0.0038	0.0019	0.0020	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.005	0.005	0.006	0.006	0.007	0.008	0.005	0.005	0.006	0.006	0.007	0.008	0.005	0.005	0.006	0.006	0.007	0.008	0.005	0.005	0.006	0.006	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0010	0.0010	0.0005	0.0006	0.0001	0.0001	0.0010	0.0010	0.0005	0.0006	0.0001	0.0001	0.0010	0.0010	0.0005	0.0006	0.0001	0.0050	0.0041	0.0041	0.0041	0.0040	0.0046
Silicon (Si)	mg/L	-	-	9	6	6	7	7	8	9	6	6	7	7	8	9	6	6	7	7	8	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.006	0.005	0.005	0.004	0.005	0.006	0.006	0.005	0.005	0.004	0.005	0.006	0.006	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.005	0.005	0.005	0.005	0.002	0.002	0.005	0.005	0.005	0.005	0.002	0.002	0.005	0.005	0.005	0.005	0.002	0.100	0.066	0.066	0.075	0.072	0.092
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.003	0.003	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.004	0.004	0.003	0.003	0.002	0.003	0.004	0.004	0.003	0.003	0.002	0.003	0.004	0.004	0.003	0.003	0.002	0.014	0.011	0.011	0.011	0.011	0.013

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-5 Water Quality Results From Mine Area 1,000 m Downstream of Clarification Pond Outlets (continued)

Torotorofotsy River 1,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	40	42	41	44	45	45	40	42	41	44	45	45	40	42	41	44	33	33	30	30	30	33
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.18	0.18	0.16	0.16	0.16	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.4	1.4	1.4	1.4	1.4	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.5	2.5	2.5	2.6	2.6	2.6	2.5	2.5	2.5	2.6	2.6	2.6	2.5	2.5	2.5	2.6	3.2	3.2	3.0	3.1	3.1	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7	7	6	7	7	7
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.9	0.9	0.8	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.8	2.6	2.6	2.6	2.7	2.8	2.8	2.6	2.6	2.6	2.7	2.8	2.8	2.6	2.6	2.6	2.7	1.3	1.3	1.3	1.3	1.3	1.3
Sulphate (SO ₄)	mg/L	-	-	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0016	0.0014	0.0014	0.0003	0.0003	0.0003	0.0016	0.0014	0.0014	0.0003	0.0003	0.0003	0.0016	0.0014	0.0014	0.0003	0.0500	0.0500	0.0455	0.0465	0.0462	0.0498
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0006	0.0003	0.0005	0.0002	0.0002	0.0002	0.0006	0.0003	0.0005	0.0002	0.0002	0.0002	0.0006	0.0003	0.0005	0.0002	0.0055	0.0055	0.0052	0.0052	0.0053	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.026	0.014	0.023	0.013	0.013	0.013	0.026	0.014	0.023	0.013	0.013	0.013	0.026	0.014	0.023	0.013	0.025	0.025	0.037	0.032	0.033	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.007	0.007	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0050	0.0050	0.0045	0.0047	0.0046	0.0050
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.031	0.010	0.029	0.008	0.008	0.008	0.031	0.010	0.029	0.008	0.008	0.008	0.031	0.010	0.029	0.008	0.006	0.006	0.030	0.021	0.028	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.3	1.3	1.3	1.4	1.4	1.4	1.3	1.3	1.3	1.4	1.4	1.4	1.3	1.3	1.3	1.4	1.1	1.1	1.0	1.1	1.1	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.050	0.050	0.045	0.046	0.046	0.050
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.07	0.07	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0018	0.0006	0.0015	0.0005	0.0005	0.0005	0.0018	0.0006	0.0015	0.0005	0.0005	0.0005	0.0018	0.0006	0.0015	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0005	0.0002	0.0004	0.0001	0.0001	0.0001	0.0005	0.0002	0.0004	0.0001	0.0001	0.0001	0.0005	0.0002	0.0004	0.0001	0.0050	0.0050	0.0048	0.0048	0.0049	0.0050
Silicon (Si)	mg/L	-	-	9	9	8	9	8	9	9	9	8	9	8	9	9	9	8	9	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.006	0.005	0.005	0.004	0.005	0.005	0.006	0.005	0.005	0.004	0.005	0.005	0.006	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.004	0.004	0.004	0.002	0.002	0.002	0.004	0.004	0.004	0.002	0.002	0.002	0.004	0.004	0.004	0.002	0.100	0.100	0.091	0.093	0.092	0.100
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.014	0.014	0.013	0.013	0.013	0.014

Notes

1 World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2 Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3 Based on the un-ionized portion of ammonia.

4 Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5 Based on long-term exposure.

6 Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7 Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8 Based on an alkalinity value of less than 60 mg/L.

9 Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10 Based on the dissolved form of this metal.

11 Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12 Based on a dissolved saturation of at least 80%.

13 Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-5 Water Quality Results From Mine Area 1,000 m Downstream of Clarification Pond Outlets (continued)

Sakalava River 1,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	41	37	41	44	45	45	41	37	41	44	45	45	41	37	41	44	33	33	29	28	29	32
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.18	0.18	0.15	0.14	0.15	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6	1.4	1.4	1.3	1.4	1.3	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.5	2.4	2.4	2.6	2.6	2.6	2.5	2.4	2.4	2.6	2.6	2.6	2.5	2.4	2.4	2.6	3.2	3.2	2.9	2.9	2.9	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	7	8	8	8	8	8	7	8	8	8	8	8	7	8	8	7	7	6	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7	0.9	0.9	0.8	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7	1.3	1.3	1.2	1.3	1.2	1.3
Sulphate (SO ₄)	mg/L	-	-	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0021	0.0020	0.0017	0.0003	0.0003	0.0003	0.0021	0.0020	0.0017	0.0003	0.0003	0.0003	0.0021	0.0020	0.0017	0.0003	0.0500	0.0500	0.0443	0.0425	0.0449	0.0493
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0003	0.0007	0.0003	0.0002	0.0002	0.0002	0.0003	0.0007	0.0003	0.0002	0.0002	0.0002	0.0003	0.0007	0.0003	0.0002	0.0055	0.0055	0.0050	0.0050	0.0050	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.013	0.030	0.013	0.013	0.013	0.013	0.013	0.030	0.013	0.013	0.013	0.013	0.013	0.030	0.013	0.013	0.025	0.025	0.033	0.040	0.030	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.007	0.007	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0050	0.0050	0.0044	0.0043	0.0045	0.0049
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.008	0.046	0.009	0.008	0.008	0.008	0.008	0.046	0.009	0.008	0.008	0.008	0.008	0.046	0.009	0.008	0.006	0.006	0.027	0.045	0.018	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.005	0.005	0.004	0.004	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4	1.1	1.1	1.0	1.0	1.0	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.050	0.050	0.044	0.042	0.045	0.049
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0004	0.0004	0.0005	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0005	0.0024	0.0005	0.0005	0.0005	0.0005	0.0005	0.0024	0.0005	0.0005	0.0005	0.0005	0.0005	0.0024	0.0005	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0003	0.0007	0.0002	0.0001	0.0001	0.0001	0.0003	0.0007	0.0002	0.0001	0.0001	0.0001	0.0003	0.0007	0.0002	0.0001	0.0050	0.0050	0.0047	0.0047	0.0046	0.0049
Silicon (Si)	mg/L	-	-	9	9	8	8	8	9	9	9	8	8	8	9	9	9	8	8	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.006	0.006	0.005	0.004	0.005	0.005	0.006	0.006	0.005	0.004	0.005	0.005	0.006	0.006	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.005	0.005	0.005	0.002	0.002	0.002	0.005	0.005	0.005	0.002	0.002	0.002	0.005	0.005	0.005	0.002	0.100	0.100	0.089	0.085	0.090	0.099
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.004	0.004	0.005	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.014	0.014	0.012	0.012	0.012	0.014

Notes

1 World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2 Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3 Based on the un-ionized portion of ammonia.

4 Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5 Based on long-term exposure.

6 Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7 Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8 Based on an alkalinity value of less than 60 mg/L.

9 Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10 Based on the dissolved form of this metal.

11 Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12 Based on a dissolved saturation of at least 80%.

13 Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-5 Water Quality Results From Mine Area 1,000 m Downstream of Clarification Pond Outlets (continued)

Ankaja River 1,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	37	37	40	37	42	45	37	37	40	37	42	45	37	37	40	37	42	33	27	27	28	27	31
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05	0.18	0.14	0.14	0.14	0.14	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.4	1.5	1.5	1.6	1.5	1.5	1.4	1.5	1.5	1.6	1.5	1.5	1.5	1.5	1.5	1.4	1.3	1.3	1.3	1.3	1.3
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.04	0.04	0.04	0.04	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.3	2.3	2.4	2.4	2.5	2.6	2.3	2.3	2.4	2.4	2.5	2.6	2.3	2.3	2.4	2.4	2.5	3.2	2.8	2.8	2.8	2.8	3.1
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	7	7	7	8	8	7	7	7	7	8	8	7	7	7	7	8	7	6	6	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7	0.9	0.7	0.7	0.8	0.7	0.8
Sodium (Na)	mg/L	-	-	2.8	2.4	2.4	2.4	2.4	2.6	2.8	2.4	2.4	2.4	2.4	2.6	2.8	2.4	2.4	2.4	2.4	2.6	1.3	1.2	1.2	1.2	1.2	1.2
Sulphate (SO ₄)	mg/L	-	-	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	2	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0019	0.0020	0.0018	0.0021	0.0003	0.0003	0.0019	0.0020	0.0018	0.0021	0.0003	0.0003	0.0019	0.0020	0.0018	0.0021	0.0003	0.0500	0.0418	0.0418	0.0424	0.0419	0.0475
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0007	0.0006	0.0003	0.0007	0.0002	0.0002	0.0007	0.0006	0.0003	0.0007	0.0002	0.0002	0.0007	0.0006	0.0003	0.0007	0.0002	0.0055	0.0049	0.0049	0.0049	0.0049	0.0052
Barium (Ba)	mg/L	0.7	-	0.013	0.028	0.026	0.012	0.027	0.012	0.013	0.028	0.026	0.012	0.027	0.012	0.013	0.028	0.026	0.012	0.027	0.012	0.025	0.037	0.036	0.034	0.037	0.024
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.006	0.006	0.006	0.006	0.006
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0050	0.0042	0.0042	0.0042	0.0042	0.0047
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.039	0.033	0.007	0.039	0.007	0.008	0.039	0.033	0.007	0.039	0.007	0.008	0.039	0.033	0.008	0.039	0.007	0.006	0.038	0.031	0.033	0.038	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.005	0.004	0.004	0.004	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.2	1.2	1.3	1.2	1.3	1.4	1.2	1.2	1.3	1.2	1.3	1.4	1.2	1.2	1.3	1.2	1.3	1.1	1.0	1.0	1.0	1.0	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.050	0.041	0.041	0.042	0.042	0.047
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.06	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.06	0.07	0.06	0.06	0.06	0.06	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0021	0.0019	0.0005	0.0020	0.0005	0.0005	0.0021	0.0019	0.0005	0.0020	0.0005	0.0005	0.0021	0.0019	0.0005	0.0020	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0006	0.0006	0.0002	0.0006	0.0001	0.0001	0.0006	0.0006	0.0002	0.0006	0.0001	0.0001	0.0006	0.0006	0.0002	0.0006	0.0001	0.0050	0.0045	0.0045	0.0045	0.0046	0.0047
Silicon (Si)	mg/L	-	-	9	7	7	8	8	9	9	7	7	8	8	9	9	7	7	8	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.006	0.005	0.006	0.004	0.005	0.006	0.006	0.005	0.006	0.004	0.005	0.006	0.006	0.005	0.006	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.005	0.005	0.005	0.005	0.002	0.002	0.005	0.005	0.005	0.005	0.002	0.002	0.005	0.005	0.005	0.005	0.002	0.100	0.084	0.084	0.085	0.084	0.095
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.004	0.004	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.014	0.012	0.012	0.012	0.012	0.013

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-6 Water Quality Results From Mine Area 1,500 m Downstream of Clarification Pond Outlets

Antsahalava River 1,500 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	25	23	25	24	33	33	25	23	25	24	33	33	25	23	25	24	33	45	34	31	33	32	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.13	0.11	0.12	0.12	0.17	0.18	0.13	0.11	0.12	0.12	0.17	0.18	0.13	0.11	0.12	0.12	0.17	0.05	0.04	0.03	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.5	1.5	1.5	1.4	1.4	1.4	1.5	1.5	1.5	1.4	1.4	1.4	1.5	1.5	1.5	1.4	1.6	1.6	1.7	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	3.2	2.8	2.7	2.8	2.7	3.2	3.2	2.8	2.7	2.8	2.7	3.2	3.2	2.8	2.7	2.8	2.7	3.2	2.6	2.3	2.3	2.4	2.3	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.06	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	5	5	5	5	7	7	5	5	5	5	7	7	5	5	5	5	7	8	6	6	6	6	8
Potassium (K)	mg/L	-	-	0.9	0.7	0.6	0.7	0.6	0.9	0.9	0.7	0.6	0.7	0.6	0.9	0.9	0.7	0.6	0.7	0.6	0.9	0.8	0.6	0.5	0.6	0.6	0.8
Sodium (Na)	mg/L	-	-	1.3	1.8	2.1	1.9	2.0	1.3	1.3	1.8	2.1	1.9	2.0	1.3	1.3	1.8	2.1	1.8	1.9	1.3	2.8	2.9	3.0	2.9	2.9	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	3	2	2	2	2	2	3	2	2	2	2	2	3	2	2	2	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0379	0.0341	0.0374	0.0356	0.0496	0.0500	0.0380	0.0341	0.0374	0.0358	0.0496	0.0500	0.0380	0.0342	0.0375	0.0362	0.0496	0.0003	0.0023	0.0027	0.0025	0.0026	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0050	0.0049	0.0050	0.0050	0.0054	0.0055	0.0050	0.0049	0.0050	0.0050	0.0054	0.0055	0.0050	0.0049	0.0050	0.0050	0.0054	0.0002	0.0012	0.0016	0.0012	0.0014	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.072	0.096	0.076	0.086	0.025	0.025	0.072	0.096	0.076	0.085	0.025	0.025	0.072	0.096	0.076	0.084	0.025	0.013	0.063	0.086	0.066	0.073	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.005	0.005	0.005	0.005	0.005	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0038	0.0034	0.0037	0.0036	0.0050	0.0050	0.0038	0.0034	0.0037	0.0036	0.0050	0.0050	0.0038	0.0034	0.0038	0.0036	0.0050	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.020	0.021	0.020	0.021	0.006	0.006	0.020	0.021	0.019	0.020	0.006	0.006	0.020	0.021	0.019	0.020	0.006	0.008	0.021	0.021	0.020	0.021	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	0.9	0.8	0.8	0.8	1.1	1.1	0.9	0.8	0.8	0.8	1.1	1.1	0.9	0.8	0.8	0.8	1.1	1.4	1.0	0.9	1.0	1.0	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.037	0.033	0.036	0.034	0.050	0.050	0.037	0.033	0.036	0.035	0.050	0.050	0.037	0.033	0.037	0.035	0.050	0.005	0.005	0.004	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.05	0.05	0.05	0.05	0.07	0.07	0.05	0.05	0.05	0.05	0.07	0.07	0.05	0.05	0.05	0.05	0.07	0.06	0.05	0.04	0.05	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0043	0.0059	0.0045	0.0050	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0047	0.0047	0.0047	0.0047	0.0050	0.0050	0.0047	0.0047	0.0047	0.0047	0.0050	0.0050	0.0047	0.0047	0.0047	0.0047	0.0050	0.0001	0.0012	0.0015	0.0012	0.0013	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	7	6	7	6	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.006	0.007	0.006	0.007	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.076	0.068	0.075	0.071	0.099	0.100	0.076	0.068	0.075	0.072	0.099	0.100	0.076	0.068	0.075	0.072	0.099	0.002	0.006	0.006	0.006	0.006	0.002
Vanadium (V)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.013	0.013	0.013	0.013	0.014	0.014	0.013	0.013	0.013	0.013	0.014	0.014	0.013	0.013	0.013	0.013	0.014	0.003	0.005	0.005	0.005	0.005	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-6 Water Quality Results From Mine Area 1,500 m Downstream of Clarification Pond Outlets (continued)

Sahaviara River 1,500 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	26	26	23	24	32	33	26	26	23	24	32	33	26	26	23	24	32	45	35	36	32	34	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.14	0.13	0.12	0.12	0.17	0.18	0.14	0.13	0.12	0.12	0.17	0.18	0.14	0.13	0.12	0.13	0.17	0.05	0.04	0.04	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.3	1.3	1.4	1.4	1.4	1.4	1.3	1.3	1.4	1.4	1.4	1.4	1.3	1.3	1.4	1.4	1.4	1.6	1.5	1.5	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	3.2	2.7	2.7	2.6	2.7	3.2	3.2	2.8	2.7	2.6	2.7	3.2	3.2	2.8	2.7	2.6	2.7	3.2	2.6	2.3	2.3	2.3	2.3	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	6	6	5	5	7	7	6	6	5	5	7	7	6	6	5	5	7	8	7	7	6	6	8
Potassium (K)	mg/L	-	-	0.9	0.7	0.7	0.6	0.7	0.9	0.9	0.7	0.7	0.6	0.7	0.9	0.9	0.7	0.7	0.6	0.7	0.9	0.8	0.6	0.6	0.6	0.6	0.7
Sodium (Na)	mg/L	-	-	1.3	1.5	1.5	1.8	1.7	1.3	1.3	1.5	1.5	1.8	1.7	1.3	1.3	1.5	1.5	1.8	1.7	1.3	2.8	2.6	2.6	2.8	2.7	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0397	0.0392	0.0348	0.0367	0.0492	0.0500	0.0399	0.0393	0.0349	0.0368	0.0492	0.0500	0.0400	0.0394	0.0351	0.0369	0.0492	0.0003	0.0015	0.0014	0.0017	0.0014	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0048	0.0048	0.0047	0.0047	0.0054	0.0055	0.0048	0.0048	0.0047	0.0048	0.0054	0.0055	0.0048	0.0048	0.0048	0.0048	0.0054	0.0002	0.0007	0.0007	0.0011	0.0009	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.051	0.053	0.080	0.067	0.025	0.025	0.051	0.052	0.080	0.067	0.025	0.025	0.050	0.052	0.079	0.067	0.025	0.013	0.041	0.041	0.066	0.052	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0040	0.0039	0.0035	0.0037	0.0049	0.0050	0.0040	0.0039	0.0035	0.0037	0.0049	0.0050	0.0040	0.0039	0.0035	0.0037	0.0049	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.012	0.012	0.014	0.013	0.006	0.006	0.012	0.012	0.014	0.013	0.006	0.006	0.012	0.012	0.014	0.013	0.006	0.008	0.013	0.013	0.014	0.013	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.004	0.004	0.003	0.004	0.005	0.005	0.004	0.004	0.003	0.004	0.005	0.005	0.004	0.004	0.003	0.004	0.005	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.003	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.003	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	0.9	0.9	0.8	0.8	1.1	1.1	0.9	0.9	0.8	0.8	1.1	1.1	0.9	0.9	0.8	0.8	1.1	1.4	1.1	1.1	1.0	1.1	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.039	0.039	0.034	0.036	0.049	0.050	0.039	0.039	0.034	0.036	0.049	0.050	0.039	0.039	0.034	0.036	0.049	0.005	0.005	0.005	0.004	0.004	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.06	0.06	0.05	0.05	0.07	0.07	0.06	0.06	0.05	0.05	0.07	0.07	0.06	0.06	0.05	0.05	0.07	0.06	0.05	0.05	0.05	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0026	0.0026	0.0043	0.0033	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0045	0.0045	0.0045	0.0044	0.0049	0.0050	0.0045	0.0045	0.0045	0.0045	0.0049	0.0050	0.0045	0.0045	0.0045	0.0045	0.0049	0.0001	0.0007	0.0007	0.0011	0.0008	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	7	7	6	7	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.006	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.079	0.078	0.070	0.073	0.098	0.100	0.080	0.079	0.070	0.074	0.098	0.100	0.080	0.079	0.070	0.074	0.098	0.002	0.004	0.004	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.012	0.012	0.012	0.012	0.014	0.014	0.012	0.012	0.012	0.012	0.014	0.014	0.012	0.012	0.012	0.012	0.014	0.003	0.003	0.003	0.004	0.004	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-6 Water Quality Results From Mine Area 1,500 m Downstream of Clarification Pond Outlets (continued)

Sahamarirana River 1,500 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	24	24	26	25	31	33	24	24	26	25	31	33	24	24	26	25	31	45	32	33	36	35	42
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.12	0.12	0.14	0.13	0.16	0.18	0.12	0.12	0.14	0.13	0.16	0.18	0.12	0.12	0.14	0.13	0.16	0.05	0.04	0.04	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.3	1.3	1.2	1.2	1.3	1.4	1.3	1.3	1.2	1.2	1.3	1.4	1.3	1.3	1.2	1.2	1.3	1.6	1.5	1.5	1.4	1.4	1.5
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	3.2	2.6	2.6	2.7	2.6	3.0	3.2	2.6	2.6	2.7	2.6	3.0	3.2	2.6	2.6	2.7	2.6	3.0	2.6	2.2	2.2	2.2	2.2	2.5
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05
Magnesium (Mg)	mg/L	-	-	7	5	5	6	5	7	7	5	5	6	5	7	7	5	5	6	5	7	8	6	6	7	7	8
Potassium (K)	mg/L	-	-	0.9	0.7	0.6	0.7	0.7	0.8	0.9	0.7	0.6	0.7	0.7	0.8	0.9	0.7	0.6	0.7	0.7	0.8	0.8	0.6	0.6	0.6	0.6	0.7
Sodium (Na)	mg/L	-	-	1.3	1.5	1.5	1.3	1.3	1.2	1.3	1.5	1.5	1.3	1.3	1.2	1.3	1.5	1.5	1.3	1.3	1.2	2.8	2.5	2.5	2.4	2.4	2.6
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2	2	1	1	2	2	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0366	0.0360	0.0397	0.0388	0.0468	0.0500	0.0367	0.0361	0.0398	0.0387	0.0468	0.0500	0.0367	0.0364	0.0399	0.0387	0.0468	0.0003	0.0018	0.0019	0.0015	0.0015	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0046	0.0045	0.0046	0.0045	0.0051	0.0055	0.0046	0.0046	0.0046	0.0045	0.0051	0.0055	0.0046	0.0046	0.0046	0.0045	0.0051	0.0002	0.0009	0.0009	0.0005	0.0005	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.052	0.055	0.036	0.039	0.023	0.025	0.052	0.055	0.036	0.039	0.023	0.025	0.052	0.054	0.036	0.039	0.023	0.013	0.043	0.045	0.026	0.028	0.012
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006	0.006	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0037	0.0036	0.0040	0.0039	0.0047	0.0050	0.0037	0.0036	0.0040	0.0039	0.0047	0.0050	0.0037	0.0036	0.0040	0.0039	0.0047	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.018	0.019	0.010	0.008	0.006	0.006	0.018	0.019	0.010	0.008	0.006	0.006	0.018	0.018	0.010	0.008	0.006	0.008	0.019	0.019	0.011	0.009	0.007
Cobalt (Co)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.003	0.004	0.004	0.004	0.004
Iron (Fe)	mg/L	-	-	1.1	0.8	0.8	0.9	0.9	1.1	1.1	0.8	0.8	0.9	0.9	1.1	1.1	0.8	0.8	0.9	0.9	1.1	1.4	1.0	1.0	1.1	1.1	1.3
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.036	0.035	0.039	0.038	0.047	0.050	0.036	0.035	0.040	0.038	0.047	0.050	0.036	0.036	0.040	0.038	0.047	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.05	0.05	0.06	0.06	0.07	0.07	0.05	0.05	0.06	0.06	0.07	0.07	0.05	0.05	0.06	0.06	0.07	0.06	0.05	0.05	0.05	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0030	0.0031	0.0016	0.0016	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.006	0.006	0.007	0.008	0.006	0.006	0.006	0.006	0.007	0.008	0.006	0.006	0.006	0.006	0.007	0.008	0.006	0.006	0.006	0.006	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0043	0.0043	0.0043	0.0042	0.0047	0.0050	0.0043	0.0043	0.0043	0.0042	0.0047	0.0050	0.0043	0.0043	0.0043	0.0042	0.0047	0.0001	0.0008	0.0008	0.0004	0.0005	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	7	7	7	7	8
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.073	0.072	0.079	0.078	0.094	0.100	0.073	0.072	0.080	0.077	0.094	0.100	0.073	0.073	0.080	0.077	0.094	0.002	0.005	0.005	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.011	0.011	0.011	0.011	0.013	0.014	0.012	0.011	0.012	0.011	0.013	0.014	0.012	0.012	0.012	0.011	0.013	0.003	0.004	0.004	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-6 Water Quality Results From Mine Area 1,500 m Downstream of Clarification Pond Outlets (continued)

Torotorofotsy River 1,500 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	33	30	30	30	33	33	33	30	31	30	33	33	33	30	31	30	33	45	45	40	43	41	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.18	0.16	0.16	0.16	0.17	0.18	0.18	0.16	0.16	0.16	0.17	0.18	0.18	0.16	0.16	0.16	0.17	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.2	3.0	3.1	3.1	3.2	3.2	3.2	3.0	3.1	3.1	3.2	3.2	3.2	3.0	3.1	3.1	3.2	2.6	2.6	2.5	2.6	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	7	7	6	7	7	7	7	7	6	7	7	7	7	7	6	7	7	7	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.9	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.9	0.8	0.8	0.7	0.7	0.8	
Sodium (Na)	mg/L	-	-	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	2.8	2.8	2.6	2.6	2.6	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0500	0.0458	0.0463	0.0465	0.0498	0.0500	0.0500	0.0458	0.0468	0.0465	0.0498	0.0500	0.0500	0.0458	0.0475	0.0465	0.0498	0.0003	0.0003	0.0015	0.0013	0.0014	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0002	0.0002	0.0005	0.0003	0.0005	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.025	0.036	0.033	0.033	0.025	0.025	0.025	0.036	0.031	0.033	0.025	0.025	0.025	0.036	0.029	0.033	0.025	0.013	0.013	0.025	0.014	0.022	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0050	0.0046	0.0046	0.0046	0.0050	0.0050	0.0050	0.0046	0.0047	0.0046	0.0050	0.0050	0.0050	0.0046	0.0047	0.0046	0.0050	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.006	0.028	0.024	0.026	0.006	0.006	0.006	0.028	0.020	0.026	0.006	0.006	0.006	0.028	0.014	0.026	0.006	0.008	0.008	0.029	0.010	0.027	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.4	1.4	1.3	1.4	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.050	0.046	0.046	0.046	0.050	0.050	0.050	0.046	0.047	0.046	0.050	0.050	0.050	0.046	0.047	0.046	0.050	0.005	0.005	0.005	0.006	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0005	0.0017	0.0006	0.0014	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.008	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0001	0.0001	0.0005	0.0002	0.0004	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	9	8	9	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.100	0.092	0.093	0.093	0.100	0.100	0.100	0.092	0.094	0.093	0.100	0.100	0.100	0.092	0.095	0.093	0.100	0.002	0.002	0.004	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-6 Water Quality Results From Mine Area 1,500 m Downstream of Clarification Pond Outlets (continued)

Torotorofotsy River 1,500 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	33	30	30	30	33	33	33	30	31	30	33	33	33	30	31	30	33	45	45	40	43	41	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.18	0.16	0.16	0.16	0.17	0.18	0.18	0.16	0.16	0.16	0.17	0.18	0.18	0.16	0.16	0.16	0.17	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.2	3.0	3.1	3.1	3.2	3.2	3.2	3.0	3.1	3.1	3.2	3.2	3.2	3.0	3.1	3.1	3.2	2.6	2.6	2.5	2.6	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	7	7	6	7	7	7	7	7	6	7	7	7	7	7	6	7	7	7	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.9	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.9	0.8	0.8	0.7	0.7	0.8	
Sodium (Na)	mg/L	-	-	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	2.8	2.8	2.6	2.6	2.6	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0500	0.0458	0.0463	0.0465	0.0498	0.0500	0.0500	0.0458	0.0468	0.0465	0.0498	0.0500	0.0500	0.0458	0.0475	0.0465	0.0498	0.0003	0.0003	0.0015	0.0013	0.0014	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0002	0.0002	0.0005	0.0003	0.0005	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.025	0.036	0.033	0.033	0.025	0.025	0.025	0.036	0.031	0.033	0.025	0.025	0.025	0.036	0.029	0.033	0.025	0.013	0.013	0.025	0.014	0.022	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0050	0.0046	0.0046	0.0046	0.0050	0.0050	0.0050	0.0046	0.0047	0.0046	0.0050	0.0050	0.0050	0.0046	0.0047	0.0046	0.0050	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.006	0.028	0.024	0.026	0.006	0.006	0.006	0.028	0.020	0.026	0.006	0.006	0.006	0.028	0.014	0.026	0.006	0.008	0.008	0.029	0.010	0.027	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.4	1.4	1.3	1.4	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.050	0.046	0.046	0.046	0.050	0.050	0.050	0.046	0.047	0.046	0.050	0.050	0.050	0.046	0.047	0.046	0.050	0.005	0.005	0.005	0.006	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0005	0.0017	0.0006	0.0014	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.008	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0001	0.0001	0.0005	0.0002	0.0004	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	9	8	9	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.100	0.092	0.093	0.093	0.100	0.100	0.100	0.092	0.094	0.093	0.100	0.100	0.100	0.092	0.095	0.093	0.100	0.002	0.002	0.004	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-6 Water Quality Results From Mine Area 1,500 m Downstream of Clarification Pond Outlets (continued)

Ankaja River 1,500 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	28	27	28	28	31	33	28	28	28	28	31	33	28	28	28	28	31	45	37	37	40	37	42
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.14	0.14	0.15	0.14	0.17	0.18	0.14	0.14	0.15	0.14	0.17	0.18	0.14	0.14	0.15	0.14	0.17	0.05	0.04	0.04	0.05	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.6	1.5	1.5	1.5	1.5	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	2.9	2.8	2.9	2.9	3.1	3.2	2.9	2.8	2.9	2.9	3.1	3.2	2.9	2.8	2.9	2.9	3.1	2.6	2.4	2.4	2.4	2.4	2.5
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	6	6	6	6	7	7	6	6	6	6	7	7	6	6	6	6	7	8	7	7	8	7	8
Potassium (K)	mg/L	-	-	0.9	0.7	0.7	0.8	0.8	0.9	0.9	0.7	0.8	0.8	0.8	0.9	0.9	0.7	0.8	0.8	0.8	0.9	0.8	0.6	0.6	0.7	0.6	0.7
Sodium (Na)	mg/L	-	-	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.2	1.2	1.2	1.2	1.2	2.8	2.4	2.4	2.5	2.4	2.6
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2	2	1	1	2	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0424	0.0420	0.0428	0.0424	0.0477	0.0500	0.0424	0.0424	0.0430	0.0424	0.0477	0.0500	0.0424	0.0424	0.0433	0.0424	0.0477	0.0003	0.0018	0.0018	0.0017	0.0020	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0049	0.0049	0.0049	0.0049	0.0052	0.0055	0.0049	0.0049	0.0049	0.0049	0.0052	0.0055	0.0049	0.0049	0.0049	0.0049	0.0052	0.0002	0.0006	0.0006	0.0003	0.0006	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.037	0.037	0.035	0.036	0.024	0.025	0.037	0.035	0.034	0.036	0.024	0.025	0.037	0.035	0.032	0.036	0.024	0.013	0.027	0.025	0.012	0.026	0.012
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006	0.006	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0042	0.0042	0.0043	0.0042	0.0048	0.0050	0.0042	0.0042	0.0043	0.0042	0.0048	0.0050	0.0042	0.0042	0.0043	0.0042	0.0048	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.035	0.033	0.033	0.036	0.006	0.006	0.035	0.029	0.031	0.036	0.006	0.006	0.035	0.029	0.028	0.036	0.006	0.008	0.037	0.031	0.007	0.037	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.002	0.001	0.001	0.002	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.0	1.0	1.0	1.1	1.4	1.2	1.2	1.3	1.2	1.3
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.042	0.042	0.042	0.042	0.048	0.050	0.042	0.042	0.043	0.042	0.048	0.050	0.042	0.042	0.043	0.042	0.048	0.005	0.005	0.005	0.006	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.06	0.05	0.05	0.06	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0019	0.0018	0.0005	0.0019	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0046	0.0045	0.0046	0.0046	0.0048	0.0050	0.0046	0.0045	0.0046	0.0046	0.0048	0.0050	0.0046	0.0045	0.0046	0.0046	0.0048	0.0001	0.0006	0.0005	0.0002	0.0006	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	8	8	8	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.006	0.005	0.005	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.085	0.084	0.086	0.085	0.095	0.100	0.085	0.085	0.086	0.085	0.095	0.100	0.085	0.085	0.087	0.085	0.095	0.002	0.005	0.005	0.005	0.005	0.002
Vanadium (V)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.012	0.012	0.012	0.012	0.013	0.014	0.012	0.012	0.012	0.012	0.013	0.014	0.012	0.012	0.012	0.012	0.013	0.003	0.003	0.003	0.002	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-6 Water Quality Results From Mine Area 1,500 m Downstream of Clarification Pond Outlets (continued)

Antsahalava River 1,500 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	34	31	33	32	44	45	34	31	33	32	44	45	34	31	33	32	44	45	34	31	33	32	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.03	0.04	0.04	0.05	0.05	0.04	0.03	0.04	0.04	0.05	0.05	0.04	0.03	0.04	0.04	0.05	0.05	0.04	0.03	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	2.6	2.3	2.3	2.4	2.3	2.6	2.6	2.3	2.3	2.4	2.3	2.6	2.6	2.3	2.3	2.4	2.3	2.6	2.6	2.3	2.3	2.4	2.3	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	6	6	6	6	8	8	6	6	6	6	8	8	6	6	6	6	8	8	6	6	6	6	8
Potassium (K)	mg/L	-	-	0.8	0.6	0.5	0.6	0.6	0.8	0.8	0.6	0.5	0.6	0.6	0.8	0.8	0.6	0.5	0.6	0.6	0.8	0.8	0.6	0.5	0.6	0.6	0.8
Sodium (Na)	mg/L	-	-	2.8	2.9	3.0	2.9	2.9	2.7	2.8	2.9	3.0	2.9	2.9	2.7	2.8	2.9	3.0	2.9	2.9	2.7	2.8	2.9	3.0	2.9	2.9	2.7
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0023	0.0027	0.0025	0.0026	0.0003	0.0003	0.0023	0.0027	0.0025	0.0026	0.0003	0.0003	0.0023	0.0027	0.0025	0.0026	0.0003	0.0003	0.0023	0.0027	0.0025	0.0026	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0012	0.0016	0.0012	0.0014	0.0002	0.0002	0.0012	0.0016	0.0012	0.0014	0.0002	0.0002	0.0012	0.0016	0.0012	0.0014	0.0002	0.0002	0.0012	0.0016	0.0012	0.0014	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.063	0.086	0.066	0.073	0.013	0.013	0.063	0.086	0.066	0.073	0.013	0.013	0.063	0.086	0.066	0.073	0.013	0.013	0.063	0.086	0.066	0.073	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.021	0.021	0.020	0.021	0.008	0.008	0.021	0.021	0.020	0.021	0.008	0.008	0.021	0.021	0.020	0.021	0.008	0.008	0.021	0.021	0.020	0.021	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.0	0.9	1.0	1.0	1.4	1.4	1.0	0.9	1.0	1.0	1.4	1.4	1.0	0.9	1.0	1.0	1.4	1.4	1.0	0.9	1.0	1.0	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.04	0.05	0.05	0.06	0.06	0.05	0.04	0.05	0.05	0.06	0.06	0.05	0.04	0.05	0.05	0.06	0.06	0.05	0.04	0.05	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0043	0.0059	0.0045	0.0050	0.0005	0.0005	0.0043	0.0059	0.0045	0.0050	0.0005	0.0005	0.0043	0.0059	0.0045	0.0050	0.0005	0.0005	0.0043	0.0059	0.0045	0.0050	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0012	0.0015	0.0012	0.0013	0.0001	0.0001	0.0012	0.0015	0.0012	0.0013	0.0001	0.0001	0.0012	0.0015	0.0012	0.0013	0.0001	0.0001	0.0012	0.0015	0.0012	0.0013	0.0001
Silicon (Si)	mg/L	-	-	9	7	6	7	6	9	9	7	6	7	6	9	9	7	6	7	6	9	9	7	6	7	6	9
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.007	0.006	0.007	0.004	0.005	0.006	0.007	0.006	0.007	0.004	0.005	0.006	0.007	0.006	0.007	0.004	0.005	0.006	0.007	0.006	0.007	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.006	0.006	0.006	0.006	0.002	0.002	0.006	0.006	0.006	0.006	0.002	0.002	0.006	0.006	0.006	0.006	0.002	0.002	0.006	0.006	0.006	0.006	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.005	0.005	0.005	0.005	0.002	0.003	0.005	0.005	0.005	0.005	0.002	0.003	0.005	0.005	0.005	0.005	0.002	0.003	0.005	0.005	0.005	0.005	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-6 Water Quality Results From Mine Area 1,500 m Downstream of Clarification Pond Outlets (continued)

Sahaviara River 1,500 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	35	36	32	34	44	45	35	36	32	34	44	45	35	36	32	34	44	45	35	36	32	34	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.6	1.6	1.6	1.6	1.5	1.5	1.6	1.6	1.6	1.6	1.5	1.5	1.6	1.6	1.6	1.6	1.5	1.5	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	2.6	2.3	2.3	2.3	2.3	2.6	2.6	2.3	2.3	2.3	2.3	2.6	2.6	2.3	2.3	2.3	2.3	2.6	2.6	2.3	2.3	2.3	2.3	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	7	6	6	8	8	7	7	6	6	8	8	7	7	6	6	8	8	7	7	6	6	8
Potassium (K)	mg/L	-	-	0.8	0.6	0.6	0.6	0.6	0.7	0.8	0.6	0.6	0.6	0.6	0.7	0.8	0.6	0.6	0.6	0.6	0.7	0.8	0.6	0.6	0.6	0.6	0.7
Sodium (Na)	mg/L	-	-	2.8	2.6	2.6	2.8	2.7	2.7	2.8	2.6	2.6	2.8	2.7	2.7	2.8	2.6	2.6	2.8	2.7	2.7	2.8	2.6	2.6	2.8	2.7	2.7
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0015	0.0014	0.0017	0.0014	0.0003	0.0003	0.0015	0.0014	0.0017	0.0014	0.0003	0.0003	0.0015	0.0014	0.0017	0.0014	0.0003	0.0003	0.0015	0.0014	0.0017	0.0014	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0007	0.0007	0.0011	0.0009	0.0002	0.0002	0.0007	0.0007	0.0011	0.0009	0.0002	0.0002	0.0007	0.0007	0.0011	0.0009	0.0002	0.0002	0.0007	0.0007	0.0011	0.0009	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.041	0.041	0.066	0.052	0.013	0.013	0.041	0.041	0.066	0.052	0.013	0.013	0.041	0.041	0.066	0.052	0.013	0.013	0.041	0.041	0.066	0.052	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.013	0.013	0.014	0.013	0.008	0.008	0.013	0.013	0.014	0.013	0.008	0.008	0.013	0.013	0.014	0.013	0.008	0.008	0.013	0.013	0.014	0.013	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.003	0.004	0.005	0.005	0.004	0.004	0.003	0.004	0.005	0.005	0.004	0.004	0.003	0.004	0.005	0.005	0.004	0.004	0.003	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.1	1.1	1.0	1.1	1.4	1.4	1.1	1.1	1.0	1.1	1.4	1.4	1.1	1.1	1.0	1.1	1.4	1.4	1.1	1.1	1.0	1.1	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0026	0.0026	0.0043	0.0033	0.0005	0.0005	0.0026	0.0026	0.0043	0.0033	0.0005	0.0005	0.0026	0.0026	0.0043	0.0033	0.0005	0.0005	0.0026	0.0026	0.0043	0.0033	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0007	0.0007	0.0011	0.0008	0.0001	0.0001	0.0007	0.0007	0.0011	0.0008	0.0001	0.0001	0.0007	0.0007	0.0011	0.0008	0.0001	0.0001	0.0007	0.0007	0.0011	0.0008	0.0001
Silicon (Si)	mg/L	-	-	9	7	7	6	7	9	9	7	7	6	7	9	9	7	7	6	7	9	9	7	7	6	7	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.006	0.005	0.004	0.005	0.005	0.005	0.006	0.005	0.004	0.005	0.005	0.005	0.006	0.005	0.004	0.005	0.005	0.005	0.006	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.004	0.004	0.002	0.003	0.003	0.003	0.004	0.004	0.002	0.003	0.003	0.003	0.004	0.004	0.002	0.003	0.003	0.003	0.004	0.004	0.002

Notes

1

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2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-6 Water Quality Results From Mine Area 1,500 m Downstream of Clarification Pond Outlets (continued)

Sahamarirana River 1,500 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	32	33	36	35	42	45	32	33	36	35	42	45	32	33	36	35	42	45	32	33	36	35	42
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.4	1.4	1.5	1.6	1.5	1.5	1.4	1.4	1.5	1.6	1.5	1.5	1.4	1.4	1.5	1.6	1.5	1.5	1.4	1.4	1.5
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	2.6	2.2	2.2	2.2	2.2	2.5	2.6	2.2	2.2	2.2	2.2	2.5	2.6	2.2	2.2	2.2	2.2	2.5	2.6	2.2	2.2	2.2	2.2	2.5
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05
Magnesium (Mg)	mg/L	-	-	8	6	6	7	7	8	8	6	6	7	7	8	8	6	6	7	7	8	8	6	6	7	7	8
Potassium (K)	mg/L	-	-	0.8	0.6	0.6	0.6	0.6	0.7	0.8	0.6	0.6	0.6	0.6	0.7	0.8	0.6	0.6	0.6	0.6	0.7	0.8	0.6	0.6	0.6	0.6	0.7
Sodium (Na)	mg/L	-	-	2.8	2.5	2.5	2.4	2.4	2.6	2.8	2.5	2.5	2.4	2.4	2.6	2.8	2.5	2.5	2.4	2.4	2.6	2.8	2.5	2.5	2.4	2.4	2.6
Sulphate (SO ₄)	mg/L	-	-	1	2	2	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0018	0.0019	0.0015	0.0015	0.0003	0.0003	0.0018	0.0019	0.0015	0.0015	0.0003	0.0003	0.0018	0.0019	0.0015	0.0015	0.0003	0.0003	0.0018	0.0019	0.0015	0.0015	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0009	0.0009	0.0005	0.0005	0.0002	0.0002	0.0009	0.0009	0.0005	0.0005	0.0002	0.0002	0.0009	0.0009	0.0005	0.0005	0.0002	0.0002	0.0009	0.0009	0.0005	0.0005	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.043	0.045	0.026	0.028	0.012	0.013	0.043	0.045	0.026	0.028	0.012	0.013	0.043	0.045	0.026	0.028	0.012	0.013	0.043	0.045	0.026	0.028	0.012
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.019	0.019	0.011	0.009	0.007	0.008	0.019	0.019	0.011	0.009	0.007	0.008	0.019	0.019	0.011	0.009	0.007	0.008	0.019	0.019	0.011	0.009	0.007
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.003	0.004	0.004	0.004	0.004	0.005	0.003	0.004	0.004	0.004	0.004	0.005	0.003	0.004	0.004	0.004	0.004	0.005	0.003	0.004	0.004	0.004	0.004
Iron (Fe)	mg/L	-	-	1.4	1.0	1.0	1.1	1.1	1.3	1.4	1.0	1.0	1.1	1.1	1.3	1.4	1.0	1.0	1.1	1.1	1.3	1.4	1.0	1.0	1.1	1.1	1.3
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0030	0.0031	0.0016	0.0016	0.0005	0.0005	0.0030	0.0031	0.0016	0.0016	0.0005	0.0005	0.0030	0.0031	0.0016	0.0016	0.0005	0.0005	0.0030	0.0031	0.0016	0.0016	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.006	0.006	0.007	0.008	0.006	0.006	0.006	0.006	0.007	0.008	0.006	0.006	0.006	0.006	0.007	0.008	0.006	0.006	0.006	0.006	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0008	0.0008	0.0004	0.0005	0.0001	0.0001	0.0008	0.0008	0.0004	0.0005	0.0001	0.0001	0.0008	0.0008	0.0004	0.0005	0.0001	0.0001	0.0008	0.0008	0.0004	0.0005	0.0001
Silicon (Si)	mg/L	-	-	9	7	7	7	7	8	9	7	7	7	7	8	9	7	7	7	7	8	9	7	7	7	7	8
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.005	0.005	0.004	0.004	0.002	0.002	0.005	0.005	0.004	0.004	0.002	0.002	0.005	0.005	0.004	0.004	0.002	0.002	0.005	0.005	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.004	0.004	0.003	0.003	0.002	0.003	0.004	0.004	0.003	0.003	0.002	0.003	0.004	0.004	0.003	0.003	0.002	0.003	0.004	0.004	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-6 Water Quality Results From Mine Area 1,500 m Downstream of Clarification Pond Outlets (continued)

Torotorofotsy River 1,500 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	40	43	41	44	45	45	40	43	41	44	45	45	40	43	41	44	45	45	40	43	41	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.5	2.6	2.5	2.6	2.6	2.6	2.5	2.6	2.5	2.6	2.6	2.6	2.5	2.6	2.5	2.6	2.6	2.6	2.5	2.6	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	2.8	2.8	2.6	2.6	2.6	2.7	2.8	2.8	2.6	2.6	2.6	2.7	2.8	2.8	2.6	2.6	2.6	2.7	2.8	2.8	2.6	2.6	2.6	2.7
Sulphate (SO ₄)	mg/L	-	-	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0015	0.0013	0.0014	0.0003	0.0003	0.0003	0.0015	0.0013	0.0014	0.0003	0.0003	0.0003	0.0015	0.0013	0.0014	0.0003	0.0003	0.0003	0.0015	0.0013	0.0014	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0005	0.0003	0.0005	0.0002	0.0002	0.0002	0.0005	0.0003	0.0005	0.0002	0.0002	0.0002	0.0005	0.0003	0.0005	0.0002	0.0002	0.0002	0.0005	0.0003	0.0005	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.025	0.014	0.022	0.013	0.013	0.013	0.025	0.014	0.022	0.013	0.013	0.013	0.025	0.014	0.022	0.013	0.013	0.013	0.025	0.014	0.022	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.029	0.010	0.027	0.008	0.008	0.008	0.029	0.010	0.027	0.008	0.008	0.008	0.029	0.010	0.027	0.008	0.008	0.008	0.029	0.010	0.027	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0017	0.0006	0.0014	0.0005	0.0005	0.0005	0.0017	0.0006	0.0014	0.0005	0.0005	0.0005	0.0017	0.0006	0.0014	0.0005	0.0005	0.0005	0.0017	0.0006	0.0014	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0005	0.0002	0.0004	0.0001	0.0001	0.0001	0.0005	0.0002	0.0004	0.0001	0.0001	0.0001	0.0005	0.0002	0.0004	0.0001	0.0001	0.0001	0.0005	0.0002	0.0004	0.0001
Silicon (Si)	mg/L	-	-	9	9	8	9	8	9	9	9	8	9	8	9	9	9	8	9	8	9	9	9	8	9	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.004	0.004	0.004	0.002	0.002	0.002	0.004	0.004	0.004	0.002	0.002	0.002	0.004	0.004	0.004	0.002	0.002	0.002	0.004	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-6 Water Quality Results From Mine Area 1,500 m Downstream of Clarification Pond Outlets (continued)

Sakalava River 1,500 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	41	38	41	44	45	45	41	38	41	44	45	45	41	38	41	44	45	45	41	38	41	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.5	2.4	2.5	2.6	2.6	2.6	2.5	2.4	2.5	2.6	2.6	2.6	2.5	2.4	2.5	2.6	2.6	2.6	2.5	2.4	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	7	8	8	8	8	8	7	8	8	8	8	8	7	8	8	8	8	8	7	8	8
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7
Sodium (Na)	mg/L	-	-	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7
Sulphate (SO ₄)	mg/L	-	-	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0020	0.0019	0.0016	0.0003	0.0003	0.0003	0.0020	0.0019	0.0016	0.0003	0.0003	0.0003	0.0020	0.0019	0.0016	0.0003	0.0003	0.0003	0.0020	0.0019	0.0016	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0003	0.0007	0.0003	0.0002	0.0002	0.0002	0.0003	0.0007	0.0003	0.0002	0.0002	0.0002	0.0003	0.0007	0.0003	0.0002	0.0002	0.0002	0.0003	0.0007	0.0003	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.013	0.030	0.013	0.013	0.013	0.013	0.013	0.030	0.013	0.013	0.013	0.013	0.013	0.030	0.013	0.013	0.013	0.013	0.013	0.030	0.013	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.008	0.045	0.009	0.008	0.008	0.008	0.008	0.045	0.009	0.008	0.008	0.008	0.008	0.045	0.009	0.008	0.008	0.008	0.008	0.045	0.009	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0005	0.0023	0.0005	0.0005	0.0005	0.0005	0.0005	0.0023	0.0005	0.0005	0.0005	0.0005	0.0005	0.0023	0.0005	0.0005	0.0005	0.0005	0.0005	0.0023	0.0005	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0003	0.0006	0.0002	0.0001	0.0001	0.0001	0.0003	0.0006	0.0002	0.0001	0.0001	0.0001	0.0003	0.0006	0.0002	0.0001	0.0001	0.0001	0.0003	0.0006	0.0002	0.0001
Silicon (Si)	mg/L	-	-	9	9	8	8	8	9	9	9	8	8	8	9	9	9	8	8	8	9	9	9	8	8	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.006	0.006	0.005	0.004	0.005	0.005	0.006	0.006	0.005	0.004	0.005	0.005	0.006	0.006	0.005	0.004	0.005	0.005	0.006	0.006	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.005	0.005	0.004	0.002	0.002	0.002	0.005	0.005	0.004	0.002	0.002	0.002	0.005	0.005	0.004	0.002	0.002	0.002	0.005	0.005	0.004	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-6 Water Quality Results From Mine Area 1,500 m Downstream of Clarification Pond Outlets (continued)

Ankaja River 1,500 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	37	37	40	37	42	45	37	37	40	37	42	45	37	37	40	37	42	45	37	37	40	37	42
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.4	2.4	2.4	2.4	2.5	2.6	2.4	2.4	2.4	2.4	2.5	2.6	2.4	2.4	2.4	2.4	2.5	2.6	2.4	2.4	2.4	2.4	2.5
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	7	8	7	8	8	7	7	8	7	8	8	7	7	8	7	8	8	7	7	8	7	8
Potassium (K)	mg/L	-	-	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7
Sodium (Na)	mg/L	-	-	2.8	2.4	2.4	2.5	2.4	2.6	2.8	2.4	2.4	2.5	2.4	2.6	2.8	2.4	2.4	2.5	2.4	2.6	2.8	2.4	2.4	2.5	2.4	2.6
Sulphate (SO ₄)	mg/L	-	-	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0018	0.0018	0.0017	0.0020	0.0003	0.0003	0.0018	0.0018	0.0017	0.0020	0.0003	0.0003	0.0018	0.0018	0.0017	0.0020	0.0003	0.0003	0.0018	0.0018	0.0017	0.0020	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0006	0.0006	0.0003	0.0006	0.0002	0.0002	0.0006	0.0006	0.0003	0.0006	0.0002	0.0002	0.0006	0.0006	0.0003	0.0006	0.0002	0.0002	0.0006	0.0006	0.0003	0.0006	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.027	0.025	0.012	0.026	0.012	0.013	0.027	0.025	0.012	0.026	0.012	0.013	0.027	0.025	0.012	0.026	0.012	0.013	0.027	0.025	0.012	0.026	0.012
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.037	0.031	0.007	0.037	0.008	0.008	0.037	0.031	0.007	0.037	0.008	0.008	0.037	0.031	0.007	0.037	0.008	0.008	0.037	0.031	0.007	0.037	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.2	1.2	1.3	1.2	1.3	1.4	1.2	1.2	1.3	1.2	1.3	1.4	1.2	1.2	1.3	1.2	1.3	1.4	1.2	1.2	1.3	1.2	1.3
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.06	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0019	0.0018	0.0005	0.0019	0.0005	0.0005	0.0019	0.0018	0.0005	0.0019	0.0005	0.0005	0.0019	0.0018	0.0005	0.0019	0.0005	0.0005	0.0019	0.0018	0.0005	0.0019	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0006	0.0005	0.0002	0.0006	0.0001	0.0001	0.0006	0.0005	0.0002	0.0006	0.0001	0.0001	0.0006	0.0005	0.0002	0.0006	0.0001	0.0001	0.0006	0.0005	0.0002	0.0006	0.0001
Silicon (Si)	mg/L	-	-	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.005	0.005	0.006	0.004	0.005	0.006	0.005	0.005	0.006	0.004	0.005	0.006	0.005	0.005	0.006	0.004	0.005	0.006	0.005	0.005	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.005	0.005	0.005	0.005	0.002	0.002	0.005	0.005	0.005	0.005	0.002	0.002	0.005	0.005	0.005	0.005	0.002	0.002	0.005	0.005	0.005	0.005	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-6 Water Quality Results From Mine Area 1,500 m Downstream of Clarification Pond Outlets (continued)

Antsahalava River 1,500 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	34	31	33	32	44	45	34	31	33	32	44	45	34	31	33	32	44	33	25	23	25	24	33
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.03	0.04	0.04	0.05	0.05	0.04	0.03	0.04	0.04	0.05	0.05	0.04	0.03	0.04	0.04	0.05	0.18	0.13	0.11	0.12	0.12	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.4	1.4	1.5	1.5	1.5	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.04	0.04	0.04	0.04	0.05
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.3	2.3	2.4	2.3	2.6	2.6	2.3	2.3	2.4	2.3	2.6	2.6	2.3	2.3	2.4	2.3	2.6	3.2	2.8	2.7	2.8	2.7	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.06	0.05
Magnesium (Mg)	mg/L	-	-	8	6	6	6	6	8	8	6	6	6	6	8	8	6	6	6	6	8	7	5	5	5	5	7
Potassium (K)	mg/L	-	-	0.8	0.6	0.5	0.6	0.6	0.8	0.8	0.6	0.5	0.6	0.6	0.8	0.8	0.6	0.5	0.6	0.6	0.8	0.9	0.7	0.6	0.7	0.6	0.9
Sodium (Na)	mg/L	-	-	2.8	2.9	3.0	2.9	2.9	2.7	2.8	2.9	3.0	2.9	2.9	2.7	2.8	2.9	3.0	2.9	2.9	2.7	1.3	1.8	2.1	1.9	2.0	1.3
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	2	2	3	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0023	0.0027	0.0025	0.0026	0.0003	0.0003	0.0023	0.0027	0.0025	0.0026	0.0003	0.0003	0.0023	0.0027	0.0025	0.0026	0.0003	0.0500	0.0380	0.0341	0.0374	0.0358	0.0496
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0012	0.0016	0.0012	0.0014	0.0002	0.0002	0.0012	0.0016	0.0012	0.0014	0.0002	0.0002	0.0012	0.0016	0.0012	0.0014	0.0002	0.0055	0.0050	0.0049	0.0050	0.0050	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.063	0.086	0.066	0.073	0.013	0.013	0.063	0.086	0.066	0.073	0.013	0.013	0.063	0.086	0.066	0.073	0.013	0.025	0.072	0.096	0.076	0.085	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.007	0.006	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0050	0.0038	0.0034	0.0037	0.0036	0.0050
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.021	0.021	0.020	0.021	0.008	0.008	0.021	0.021	0.020	0.021	0.008	0.008	0.021	0.021	0.020	0.021	0.008	0.006	0.020	0.021	0.019	0.020	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.005	0.004	0.003	0.004	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.0	0.9	1.0	1.0	1.4	1.4	1.0	0.9	1.0	1.0	1.4	1.4	1.0	0.9	1.0	1.0	1.4	1.1	0.9	0.8	0.8	0.8	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.050	0.037	0.033	0.036	0.035	0.050
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.04	0.05	0.05	0.06	0.06	0.05	0.04	0.05	0.05	0.06	0.06	0.05	0.04	0.05	0.05	0.06	0.07	0.05	0.05	0.05	0.05	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0043	0.0059	0.0045	0.0050	0.0005	0.0005	0.0043	0.0059	0.0045	0.0050	0.0005	0.0005	0.0043	0.0059	0.0045	0.0050	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0012	0.0015	0.0012	0.0013	0.0001	0.0001	0.0012	0.0015	0.0012	0.0013	0.0001	0.0001	0.0012	0.0015	0.0012	0.0013	0.0001	0.0050	0.0047	0.0047	0.0047	0.0047	0.0050
Silicon (Si)	mg/L	-	-	9	7	6	7	6	9	9	7	6	7	6	9	9	7	6	7	6	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.007	0.006	0.007	0.004	0.005	0.006	0.007	0.006	0.007	0.004	0.005	0.006	0.007	0.006	0.007	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.006	0.006	0.006	0.006	0.002	0.002	0.006	0.006	0.006	0.006	0.002	0.002	0.006	0.006	0.006	0.006	0.002	0.100	0.076	0.068	0.075	0.072	0.099
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.004	0.004	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.005	0.005	0.005	0.005	0.002	0.003	0.005	0.005	0.005	0.005	0.002	0.003	0.005	0.005	0.005	0.005	0.002	0.014	0.013	0.013	0.013	0.013	0.014

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-6 Water Quality Results From Mine Area 1,500 m Downstream of Clarification Pond Outlets (continued)

Sahaviara River 1,500 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	35	36	32	34	44	45	35	36	32	34	44	45	35	36	32	34	44	33	26	26	23	24	32
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.18	0.14	0.13	0.12	0.12	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.6	1.6	1.6	1.6	1.5	1.5	1.6	1.6	1.6	1.6	1.5	1.5	1.6	1.5	1.6	1.4	1.3	1.3	1.4	1.4	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.04	0.04	0.04	0.04	0.05
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.3	2.3	2.3	2.3	2.6	2.6	2.3	2.3	2.3	2.3	2.6	2.6	2.3	2.3	2.3	2.3	2.6	3.2	2.8	2.7	2.6	2.7	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	7	6	6	8	8	7	7	6	6	8	8	7	7	6	6	8	7	6	6	5	5	7
Potassium (K)	mg/L	-	-	0.8	0.6	0.6	0.6	0.6	0.7	0.8	0.6	0.6	0.6	0.6	0.7	0.8	0.6	0.6	0.6	0.6	0.7	0.9	0.7	0.7	0.6	0.7	0.9
Sodium (Na)	mg/L	-	-	2.8	2.6	2.6	2.8	2.7	2.7	2.8	2.6	2.6	2.8	2.7	2.7	2.8	2.6	2.6	2.8	2.7	2.7	1.3	1.5	1.5	1.8	1.7	1.3
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0015	0.0014	0.0017	0.0014	0.0003	0.0003	0.0015	0.0014	0.0017	0.0014	0.0003	0.0003	0.0015	0.0014	0.0017	0.0015	0.0003	0.0500	0.0399	0.0393	0.0349	0.0368	0.0492
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0007	0.0007	0.0011	0.0009	0.0002	0.0002	0.0007	0.0007	0.0011	0.0009	0.0002	0.0002	0.0007	0.0007	0.0011	0.0009	0.0002	0.0055	0.0048	0.0048	0.0047	0.0048	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.041	0.041	0.066	0.052	0.013	0.013	0.041	0.041	0.066	0.052	0.013	0.013	0.041	0.041	0.066	0.054	0.013	0.025	0.051	0.052	0.080	0.067	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.006	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0040	0.0039	0.0035	0.0037	0.0049
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.013	0.013	0.014	0.013	0.008	0.008	0.013	0.013	0.014	0.013	0.008	0.008	0.013	0.013	0.014	0.014	0.008	0.006	0.012	0.012	0.014	0.013	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.005	0.004	0.004	0.003	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.003	0.004	0.005	0.005	0.004	0.004	0.003	0.004	0.005	0.005	0.004	0.004	0.003	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.1	1.1	1.0	1.1	1.4	1.4	1.1	1.1	1.0	1.1	1.4	1.4	1.1	1.1	1.0	1.1	1.4	1.1	0.9	0.9	0.8	0.8	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.050	0.039	0.039	0.034	0.036	0.049
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.07	0.06	0.06	0.05	0.05	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0026	0.0026	0.0043	0.0033	0.0005	0.0005	0.0026	0.0026	0.0043	0.0033	0.0005	0.0005	0.0026	0.0026	0.0043	0.0034	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0007	0.0007	0.0011	0.0008	0.0001	0.0001	0.0007	0.0007	0.0011	0.0008	0.0001	0.0001	0.0007	0.0007	0.0011	0.0009	0.0001	0.0050	0.0045	0.0045	0.0045	0.0045	0.0049
Silicon (Si)	mg/L	-	-	9	7	7	6	7	9	9	7	7	6	7	9	9	7	7	6	7	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.006	0.005	0.004	0.005	0.005	0.005	0.006	0.005	0.004	0.005	0.005	0.005	0.006	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.100	0.080	0.079	0.070	0.074	0.098
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.004	0.004	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.004	0.004	0.002	0.003	0.003	0.003	0.004	0.004	0.002	0.003	0.003	0.003	0.004	0.004	0.002	0.014	0.012	0.012	0.012	0.012	0.014

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-6 Water Quality Results From Mine Area 1,500 m Downstream of Clarification Pond Outlets (continued)

Sahamarirana River 1,500 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	32	33	36	35	42	45	32	33	36	35	42	45	32	33	36	35	42	33	24	24	26	25	31
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.18	0.12	0.12	0.14	0.13	0.16
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.4	1.4	1.5	1.6	1.5	1.5	1.4	1.4	1.5	1.6	1.5	1.5	1.4	1.4	1.5	1.4	1.3	1.3	1.2	1.2	1.3
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.04	0.04	0.04	0.04	0.05
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.2	2.2	2.2	2.2	2.5	2.6	2.2	2.2	2.2	2.2	2.5	2.6	2.2	2.2	2.2	2.2	2.5	3.2	2.6	2.6	2.7	2.6	3.0
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05
Magnesium (Mg)	mg/L	-	-	8	6	6	7	7	8	8	6	6	7	7	8	8	6	6	7	7	8	7	5	5	6	5	7
Potassium (K)	mg/L	-	-	0.8	0.6	0.6	0.6	0.6	0.7	0.8	0.6	0.6	0.6	0.6	0.7	0.8	0.6	0.6	0.6	0.6	0.7	0.9	0.7	0.6	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	2.8	2.5	2.5	2.4	2.4	2.6	2.8	2.5	2.5	2.4	2.4	2.6	2.8	2.5	2.5	2.4	2.4	2.6	1.3	1.5	1.5	1.3	1.3	1.2
Sulphate (SO ₄)	mg/L	-	-	1	2	2	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1	2	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0018	0.0019	0.0015	0.0015	0.0003	0.0003	0.0018	0.0019	0.0015	0.0015	0.0003	0.0003	0.0018	0.0019	0.0015	0.0015	0.0003	0.0500	0.0367	0.0361	0.0398	0.0387	0.0468
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0009	0.0009	0.0005	0.0005	0.0002	0.0002	0.0009	0.0009	0.0005	0.0005	0.0002	0.0002	0.0009	0.0009	0.0005	0.0005	0.0002	0.0055	0.0046	0.0046	0.0046	0.0045	0.0051
Barium (Ba)	mg/L	0.7	-	0.013	0.043	0.045	0.026	0.028	0.012	0.013	0.043	0.045	0.026	0.028	0.012	0.013	0.043	0.045	0.026	0.028	0.012	0.025	0.052	0.055	0.036	0.039	0.023
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.006	0.006	0.006	0.006	0.006
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0037	0.0036	0.0040	0.0039	0.0047
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.019	0.019	0.011	0.009	0.007	0.008	0.019	0.019	0.011	0.009	0.007	0.008	0.019	0.019	0.011	0.009	0.007	0.006	0.018	0.019	0.010	0.008	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.005	0.004	0.004	0.004	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.003	0.004	0.004	0.004	0.004	0.005	0.003	0.004	0.004	0.004	0.004	0.005	0.003	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.0	1.0	1.1	1.1	1.3	1.4	1.0	1.0	1.1	1.1	1.3	1.4	1.0	1.0	1.1	1.1	1.3	1.1	0.8	0.8	0.9	0.9	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.036	0.035	0.040	0.038	0.047
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.07	0.05	0.05	0.06	0.06	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0030	0.0031	0.0016	0.0016	0.0005	0.0005	0.0030	0.0031	0.0016	0.0016	0.0005	0.0005	0.0030	0.0031	0.0016	0.0016	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.006	0.006	0.007	0.008	0.006	0.006	0.006	0.006	0.007	0.008	0.006	0.006	0.006	0.006	0.007	0.008	0.006	0.006	0.006	0.006	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0008	0.0008	0.0004	0.0005	0.0001	0.0001	0.0008	0.0008	0.0004	0.0005	0.0001	0.0001	0.0008	0.0008	0.0004	0.0005	0.0001	0.0050	0.0043	0.0043	0.0043	0.0042	0.0047
Silicon (Si)	mg/L	-	-	9	7	7	7	7	8	9	7	7	7	7	8	9	7	7	7	7	8	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.005	0.005	0.004	0.004	0.002	0.002	0.005	0.005	0.004	0.004	0.002	0.002	0.005	0.005	0.004	0.004	0.002	0.100	0.073	0.072	0.080	0.077	0.094
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.004	0.004	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.004	0.004	0.003	0.003	0.002	0.003	0.004	0.004	0.003	0.003	0.002	0.003	0.004	0.004	0.003	0.003	0.002	0.014	0.012	0.011	0.012	0.011	0.013

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-6 Water Quality Results From Mine Area 1,500 m Downstream of Clarification Pond Outlets (continued)

Torotorofotsy River 1,500 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	40	43	41	44	45	45	40	43	41	44	45	45	40	43	41	44	33	33	30	31	30	33
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.18	0.18	0.16	0.16	0.16	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.4	1.4	1.4	1.4	1.4	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.5	2.6	2.5	2.6	2.6	2.6	2.5	2.6	2.5	2.6	2.6	2.6	2.5	2.6	2.5	2.6	3.2	3.2	3.0	3.1	3.1	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7	7	6	7	7	7
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.9	0.9	0.8	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.8	2.6	2.6	2.6	2.7	2.8	2.8	2.6	2.6	2.6	2.7	2.8	2.8	2.6	2.6	2.6	2.7	1.3	1.3	1.3	1.3	1.3	1.3
Sulphate (SO ₄)	mg/L	-	-	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0015	0.0013	0.0014	0.0003	0.0003	0.0003	0.0015	0.0013	0.0014	0.0003	0.0003	0.0003	0.0015	0.0013	0.0014	0.0003	0.0500	0.0500	0.0458	0.0468	0.0465	0.0498
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0005	0.0003	0.0005	0.0002	0.0002	0.0002	0.0005	0.0003	0.0005	0.0002	0.0002	0.0002	0.0005	0.0003	0.0005	0.0002	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.025	0.014	0.022	0.013	0.013	0.013	0.025	0.014	0.022	0.013	0.013	0.013	0.025	0.014	0.022	0.013	0.025	0.025	0.036	0.031	0.033	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.007	0.007	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0050	0.0050	0.0046	0.0047	0.0046	0.0050
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.029	0.010	0.027	0.008	0.008	0.008	0.029	0.010	0.027	0.008	0.008	0.008	0.029	0.010	0.027	0.008	0.006	0.006	0.028	0.019	0.026	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.4	1.1	1.1	1.0	1.1	1.1	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.050	0.050	0.046	0.047	0.046	0.050
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0017	0.0006	0.0014	0.0005	0.0005	0.0005	0.0017	0.0006	0.0014	0.0005	0.0005	0.0005	0.0017	0.0006	0.0014	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0005	0.0002	0.0004	0.0001	0.0001	0.0001	0.0005	0.0002	0.0004	0.0001	0.0001	0.0001	0.0005	0.0002	0.0004	0.0001	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050
Silicon (Si)	mg/L	-	-	9	9	8	9	8	9	9	9	8	9	8	9	9	9	8	9	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.004	0.004	0.004	0.002	0.002	0.002	0.004	0.004	0.004	0.002	0.002	0.002	0.004	0.004	0.004	0.002	0.100	0.100	0.092	0.094	0.093	0.100
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.014	0.014	0.013	0.013	0.013	0.014

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-6 Water Quality Results From Mine Area 1,500 m Downstream of Clarification Pond Outlets (continued)

Sakalava River 1,500 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	41	38	41	44	45	45	41	38	41	44	45	45	41	38	41	44	33	33	29	28	30	32
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.18	0.18	0.15	0.15	0.15	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6	1.4	1.4	1.3	1.4	1.3	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.5	2.4	2.5	2.6	2.6	2.6	2.5	2.4	2.5	2.6	2.6	2.6	2.5	2.4	2.5	2.6	3.2	3.2	2.9	2.9	3.0	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	7	8	8	8	8	8	7	8	8	8	8	8	7	8	8	7	7	6	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7	0.9	0.9	0.8	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7	2.8	2.8	2.5	2.5	2.5	2.7	1.3	1.3	1.2	1.3	1.2	1.3
Sulphate (SO ₄)	mg/L	-	-	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0020	0.0019	0.0016	0.0003	0.0003	0.0003	0.0020	0.0019	0.0016	0.0003	0.0003	0.0003	0.0020	0.0019	0.0016	0.0003	0.0500	0.0500	0.0446	0.0428	0.0452	0.0493
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0003	0.0007	0.0003	0.0002	0.0002	0.0002	0.0003	0.0007	0.0003	0.0002	0.0002	0.0002	0.0003	0.0007	0.0003	0.0002	0.0055	0.0055	0.0051	0.0051	0.0051	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.013	0.030	0.013	0.013	0.013	0.013	0.013	0.030	0.013	0.013	0.013	0.013	0.013	0.030	0.013	0.013	0.025	0.025	0.032	0.040	0.029	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.007	0.007	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0050	0.0050	0.0045	0.0043	0.0045	0.0049
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.008	0.045	0.009	0.008	0.008	0.008	0.008	0.045	0.009	0.008	0.008	0.008	0.008	0.045	0.009	0.008	0.006	0.006	0.026	0.043	0.017	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.005	0.005	0.004	0.004	0.005	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.005	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4	1.1	1.1	1.0	1.0	1.0	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.050	0.050	0.044	0.042	0.045	0.049
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0004	0.0004	0.0005	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0005	0.0023	0.0005	0.0005	0.0005	0.0005	0.0005	0.0023	0.0005	0.0005	0.0005	0.0005	0.0005	0.0023	0.0005	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0003	0.0006	0.0002	0.0001	0.0001	0.0001	0.0003	0.0006	0.0002	0.0001	0.0001	0.0001	0.0003	0.0006	0.0002	0.0001	0.0050	0.0050	0.0047	0.0047	0.0047	0.0049
Silicon (Si)	mg/L	-	-	9	9	8	8	8	9	9	9	8	8	8	9	9	9	8	8	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.006	0.006	0.005	0.004	0.005	0.005	0.006	0.006	0.005	0.004	0.005	0.005	0.006	0.006	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.005	0.005	0.004	0.002	0.002	0.002	0.005	0.005	0.004	0.002	0.002	0.002	0.005	0.005	0.004	0.002	0.100	0.100	0.089	0.086	0.090	0.099
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.004	0.004	0.005	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.014	0.014	0.012	0.012	0.012	0.014

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-6 Water Quality Results From Mine Area 1,500 m Downstream of Clarification Pond Outlets (continued)

Ankaja River 1,500 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	37	37	40	37	42	45	37	37	40	37	42	45	37	37	40	37	42	33	28	28	28	28	31
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05	0.18	0.14	0.14	0.15	0.14	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.4	1.3	1.3	1.3	1.3	1.3
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.04	0.04	0.04	0.04	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.4	2.4	2.4	2.4	2.5	2.6	2.4	2.4	2.4	2.4	2.5	2.6	2.4	2.4	2.4	2.4	2.5	3.2	2.9	2.8	2.9	2.9	3.1
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	8	7	7	8	7	8	8	7	7	8	7	8	8	7	7	8	7	8	7	6	6	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7	0.9	0.7	0.8	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.4	2.4	2.5	2.4	2.6	2.8	2.4	2.4	2.5	2.4	2.6	2.8	2.4	2.4	2.5	2.4	2.6	1.3	1.2	1.2	1.2	1.2	1.2
Sulphate (SO ₄)	mg/L	-	-	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	2	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0018	0.0018	0.0017	0.0020	0.0003	0.0003	0.0018	0.0018	0.0017	0.0020	0.0003	0.0003	0.0018	0.0018	0.0017	0.0020	0.0003	0.0500	0.0424	0.0424	0.0430	0.0424	0.0477
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0006	0.0006	0.0003	0.0006	0.0002	0.0002	0.0006	0.0006	0.0003	0.0006	0.0002	0.0002	0.0006	0.0006	0.0003	0.0006	0.0002	0.0055	0.0049	0.0049	0.0049	0.0049	0.0052
Barium (Ba)	mg/L	0.7	-	0.013	0.027	0.025	0.012	0.026	0.012	0.013	0.027	0.025	0.012	0.026	0.012	0.013	0.027	0.025	0.012	0.026	0.012	0.025	0.037	0.035	0.034	0.036	0.024
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.006	0.006	0.006	0.006	0.006
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0050	0.0042	0.0042	0.0043	0.0042	0.0048
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.037	0.031	0.007	0.037	0.008	0.008	0.037	0.031	0.007	0.037	0.008	0.008	0.037	0.031	0.008	0.037	0.008	0.006	0.035	0.029	0.031	0.036	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.005	0.004	0.004	0.004	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.2	1.2	1.3	1.2	1.3	1.4	1.2	1.2	1.3	1.2	1.3	1.4	1.2	1.2	1.3	1.2	1.3	1.1	1.0	1.0	1.0	1.0	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.050	0.042	0.042	0.043	0.042	0.048
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.06	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.06	0.06	0.05	0.05	0.06	0.05	0.06	0.07	0.06	0.06	0.06	0.06	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0019	0.0018	0.0005	0.0019	0.0005	0.0005	0.0019	0.0018	0.0005	0.0019	0.0005	0.0005	0.0019	0.0018	0.0005	0.0019	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0006	0.0005	0.0002	0.0006	0.0001	0.0001	0.0006	0.0005	0.0002	0.0006	0.0001	0.0001	0.0006	0.0005	0.0002	0.0006	0.0001	0.0050	0.0046	0.0045	0.0046	0.0046	0.0048
Silicon (Si)	mg/L	-	-	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.005	0.005	0.006	0.004	0.005	0.006	0.005	0.005	0.006	0.004	0.005	0.006	0.005	0.005	0.006	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.005	0.005	0.005	0.005	0.002	0.002	0.005	0.005	0.005	0.005	0.002	0.002	0.005	0.005	0.005	0.005	0.002	0.100	0.085	0.085	0.086	0.085	0.095
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.004	0.004	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.014	0.012	0.012	0.012	0.012	0.013

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-7 Water Quality Results From Mine Area 2,000 m Downstream of Clarification Pond Outlets

Antsahalava River 2,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	26	23	25	24	33	33	26	23	25	24	33	33	26	23	25	25	33	45	34	31	34	33	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.13	0.12	0.13	0.12	0.17	0.18	0.13	0.12	0.13	0.12	0.17	0.18	0.13	0.12	0.13	0.12	0.17	0.05	0.04	0.03	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.5	1.5	1.5	1.4	1.4	1.4	1.5	1.5	1.5	1.4	1.4	1.4	1.5	1.5	1.5	1.4	1.6	1.6	1.7	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	3.2	2.8	2.7	2.8	2.7	3.2	3.2	2.8	2.7	2.8	2.7	3.2	3.2	2.8	2.7	2.8	2.8	3.2	2.6	2.4	2.3	2.4	2.4	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	5	5	5	5	7	7	5	5	5	5	7	7	5	5	5	5	7	8	6	6	6	6	8
Potassium (K)	mg/L	-	-	0.9	0.7	0.6	0.7	0.6	0.9	0.9	0.7	0.6	0.7	0.7	0.9	0.9	0.7	0.6	0.7	0.7	0.9	0.8	0.6	0.5	0.6	0.6	0.8
Sodium (Na)	mg/L	-	-	1.3	1.8	2.0	1.8	1.9	1.3	1.3	1.8	2.0	1.8	1.9	1.3	1.3	1.8	2.0	1.8	1.9	1.3	2.8	2.8	3.0	2.9	2.9	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0387	0.0350	0.0381	0.0365	0.0497	0.0500	0.0388	0.0351	0.0382	0.0367	0.0497	0.0500	0.0388	0.0352	0.0383	0.0370	0.0497	0.0003	0.0022	0.0025	0.0023	0.0024	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0050	0.0050	0.0050	0.0050	0.0054	0.0055	0.0050	0.0050	0.0050	0.0050	0.0054	0.0055	0.0050	0.0050	0.0050	0.0050	0.0054	0.0002	0.0011	0.0015	0.0012	0.0013	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.069	0.092	0.073	0.082	0.025	0.025	0.069	0.092	0.073	0.082	0.025	0.025	0.069	0.091	0.073	0.080	0.025	0.013	0.060	0.081	0.063	0.069	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.005	0.005	0.005	0.005	0.005	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0039	0.0035	0.0038	0.0036	0.0050	0.0050	0.0039	0.0035	0.0038	0.0037	0.0050	0.0050	0.0039	0.0035	0.0038	0.0037	0.0050	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.019	0.020	0.019	0.020	0.006	0.006	0.019	0.020	0.019	0.019	0.006	0.006	0.019	0.020	0.019	0.019	0.006	0.008	0.020	0.020	0.019	0.020	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	0.9	0.8	0.9	0.8	1.1	1.1	0.9	0.8	0.9	0.8	1.1	1.1	0.9	0.8	0.9	0.8	1.1	1.4	1.1	1.0	1.1	1.0	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.038	0.034	0.037	0.035	0.050	0.050	0.038	0.034	0.037	0.036	0.050	0.050	0.038	0.034	0.037	0.036	0.050	0.005	0.005	0.004	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.06	0.05	0.05	0.05	0.07	0.07	0.06	0.05	0.05	0.05	0.07	0.07	0.06	0.05	0.05	0.05	0.07	0.06	0.05	0.05	0.05	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0041	0.0055	0.0042	0.0047	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0047	0.0047	0.0047	0.0047	0.0050	0.0050	0.0047	0.0047	0.0047	0.0047	0.0050	0.0050	0.0047	0.0047	0.0047	0.0047	0.0050	0.0001	0.0011	0.0014	0.0011	0.0012	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	7	6	7	7	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.006	0.007	0.006	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.077	0.070	0.076	0.073	0.099	0.100	0.078	0.070	0.076	0.073	0.099	0.100	0.078	0.070	0.077	0.074	0.099	0.002	0.005	0.006	0.006	0.006	0.002
Vanadium (V)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.013	0.013	0.013	0.013	0.014	0.014	0.013	0.013	0.013	0.013	0.014	0.014	0.013	0.013	0.013	0.013	0.014	0.003	0.004	0.005	0.004	0.005	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-7 Water Quality Results From Mine Area 2,000 m Downstream of Clarification Pond Outlets (continued)

Sahaviara River 2,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	27	27	24	25	32	33	27	27	24	25	32	33	27	27	24	25	32	45	37	37	34	36	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.14	0.14	0.12	0.13	0.17	0.18	0.14	0.14	0.12	0.13	0.17	0.18	0.14	0.14	0.12	0.13	0.17	0.05	0.04	0.04	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.3	1.3	1.4	1.4	1.4	1.4	1.3	1.3	1.4	1.4	1.4	1.4	1.3	1.3	1.4	1.4	1.4	1.6	1.5	1.5	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	3	3	4
Chloride (Cl)	mg/L	-	-	3.2	2.8	2.8	2.7	2.7	3.2	3.2	2.8	2.8	2.7	2.7	3.2	3.2	2.8	2.8	2.7	2.7	3.2	2.6	2.3	2.3	2.3	2.3	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	6	6	5	5	7	7	6	6	5	5	7	7	6	6	5	5	7	8	7	7	6	7	8
Potassium (K)	mg/L	-	-	0.9	0.7	0.7	0.7	0.7	0.9	0.9	0.7	0.7	0.7	0.7	0.9	0.9	0.7	0.7	0.7	0.7	0.9	0.8	0.6	0.6	0.6	0.6	0.7
Sodium (Na)	mg/L	-	-	1.3	1.5	1.5	1.8	1.6	1.3	1.3	1.5	1.5	1.8	1.6	1.3	1.3	1.5	1.5	1.8	1.6	1.3	2.8	2.6	2.7	2.8	2.7	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0410	0.0404	0.0365	0.0383	0.0493	0.0500	0.0412	0.0405	0.0366	0.0384	0.0493	0.0500	0.0413	0.0407	0.0368	0.0385	0.0493	0.0003	0.0013	0.0012	0.0015	0.0013	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0049	0.0049	0.0048	0.0048	0.0054	0.0055	0.0049	0.0049	0.0048	0.0048	0.0054	0.0055	0.0049	0.0049	0.0048	0.0048	0.0054	0.0002	0.0007	0.0006	0.0010	0.0008	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.048	0.049	0.074	0.062	0.025	0.025	0.047	0.049	0.074	0.062	0.025	0.025	0.047	0.049	0.073	0.062	0.025	0.013	0.038	0.037	0.059	0.047	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0041	0.0040	0.0037	0.0038	0.0049	0.0050	0.0041	0.0041	0.0037	0.0038	0.0049	0.0050	0.0041	0.0041	0.0037	0.0038	0.0049	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.011	0.012	0.013	0.012	0.006	0.006	0.011	0.011	0.013	0.012	0.006	0.006	0.011	0.011	0.013	0.012	0.006	0.008	0.012	0.012	0.013	0.013	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	0.9	0.9	0.8	0.9	1.1	1.1	0.9	0.9	0.8	0.9	1.1	1.1	0.9	0.9	0.8	0.9	1.1	1.4	1.1	1.1	1.0	1.1	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.041	0.040	0.036	0.038	0.049	0.050	0.041	0.040	0.036	0.038	0.049	0.050	0.041	0.040	0.036	0.038	0.049	0.005	0.005	0.005	0.004	0.004	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.06	0.06	0.05	0.05	0.07	0.07	0.06	0.06	0.05	0.05	0.07	0.07	0.06	0.06	0.05	0.06	0.07	0.06	0.05	0.05	0.05	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0002	0.0002	0.0002	0.0001	0.0001	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0023	0.0023	0.0038	0.0030	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.006	0.006	0.008	0.008	0.007	0.007	0.006	0.006	0.008	0.008	0.007	0.007	0.006	0.006	0.008	0.008	0.007	0.007	0.006	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0045	0.0045	0.0045	0.0045	0.0049	0.0050	0.0046	0.0045	0.0045	0.0045	0.0049	0.0050	0.0046	0.0045	0.0045	0.0045	0.0049	0.0001	0.0006	0.0006	0.0010	0.0007	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	7	7	7	7	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.082	0.081	0.073	0.077	0.099	0.100	0.082	0.081	0.073	0.077	0.099	0.100	0.083	0.081	0.074	0.077	0.099	0.002	0.004	0.004	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.012	0.012	0.012	0.012	0.014	0.014	0.012	0.012	0.012	0.012	0.014	0.014	0.012	0.012	0.012	0.012	0.014	0.003	0.003	0.003	0.004	0.004	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-7 Water Quality Results From Mine Area 2,000 m Downstream of Clarification Pond Outlets (continued)

Sahamarirana River 2,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	26	25	27	27	31	33	26	25	27	27	31	33	26	26	27	27	31	45	35	35	37	37	42
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.13	0.13	0.14	0.14	0.17	0.18	0.13	0.13	0.14	0.14	0.17	0.18	0.13	0.13	0.14	0.14	0.17	0.05	0.04	0.04	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.3	1.3	1.2	1.2	1.3	1.4	1.3	1.3	1.2	1.2	1.3	1.4	1.3	1.3	1.2	1.2	1.3	1.6	1.5	1.5	1.5	1.5	1.5
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	3	3	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	2.7	2.7	2.8	2.7	3.0	3.2	2.7	2.7	2.8	2.7	3.0	3.2	2.7	2.7	2.8	2.7	3.0	2.6	2.3	2.3	2.3	2.3	2.5
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	6	5	6	6	7	7	6	5	6	6	7	7	6	5	6	6	7	8	7	7	7	7	8
Potassium (K)	mg/L	-	-	0.9	0.7	0.7	0.7	0.7	0.8	0.9	0.7	0.7	0.7	0.7	0.8	0.9	0.7	0.7	0.7	0.7	0.8	0.8	0.6	0.6	0.6	0.6	0.7
Sodium (Na)	mg/L	-	-	1.3	1.4	1.5	1.3	1.3	1.2	1.3	1.4	1.5	1.3	1.3	1.2	1.3	1.4	1.5	1.3	1.3	1.2	2.8	2.6	2.6	2.5	2.5	2.6
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2	2	1	1	2	2	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0390	0.0384	0.0414	0.0407	0.0473	0.0500	0.0392	0.0385	0.0415	0.0407	0.0473	0.0500	0.0392	0.0388	0.0417	0.0407	0.0473	0.0003	0.0016	0.0016	0.0012	0.0012	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0047	0.0047	0.0047	0.0047	0.0052	0.0055	0.0047	0.0047	0.0047	0.0047	0.0052	0.0055	0.0047	0.0047	0.0048	0.0047	0.0052	0.0002	0.0007	0.0007	0.0004	0.0005	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.047	0.050	0.034	0.037	0.024	0.025	0.047	0.050	0.034	0.037	0.024	0.025	0.047	0.049	0.034	0.037	0.024	0.013	0.038	0.039	0.024	0.026	0.012
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006	0.006	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0039	0.0038	0.0041	0.0041	0.0047	0.0050	0.0039	0.0039	0.0042	0.0041	0.0047	0.0050	0.0039	0.0039	0.0042	0.0041	0.0047	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.016	0.017	0.010	0.008	0.006	0.006	0.016	0.016	0.010	0.008	0.006	0.006	0.016	0.016	0.010	0.008	0.006	0.008	0.017	0.017	0.011	0.009	0.007
Cobalt (Co)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.004
Iron (Fe)	mg/L	-	-	1.1	0.9	0.9	0.9	0.9	1.1	1.1	0.9	0.9	1.0	0.9	1.1	1.1	0.9	0.9	1.0	0.9	1.1	1.4	1.1	1.1	1.2	1.2	1.3
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.039	0.038	0.041	0.040	0.047	0.050	0.039	0.038	0.041	0.040	0.047	0.050	0.039	0.038	0.041	0.040	0.047	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.06	0.05	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.06	0.05	0.05	0.05	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0025	0.0026	0.0014	0.0014	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.007	0.006	0.007	0.008	0.006	0.006	0.007	0.006	0.007	0.008	0.006	0.006	0.007	0.006	0.007	0.008	0.006	0.006	0.007	0.007	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0044	0.0044	0.0044	0.0043	0.0047	0.0050	0.0044	0.0044	0.0044	0.0043	0.0047	0.0050	0.0044	0.0044	0.0044	0.0043	0.0047	0.0001	0.0007	0.0007	0.0004	0.0004	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	7	7	8	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.078	0.077	0.083	0.081	0.095	0.100	0.078	0.077	0.083	0.081	0.095	0.100	0.078	0.078	0.083	0.081	0.095	0.002	0.004	0.004	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.012	0.012	0.012	0.012	0.013	0.014	0.012	0.012	0.012	0.012	0.013	0.014	0.012	0.012	0.012	0.012	0.013	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-7 Water Quality Results From Mine Area 2,000 m Downstream of Clarification Pond Outlets (continued)

Torotorofotsy River 2,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	33	30	30	31	33	33	33	30	31	31	33	33	33	30	31	31	33	45	45	41	43	41	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.18	0.16	0.16	0.16	0.17	0.18	0.18	0.16	0.16	0.16	0.17	0.18	0.18	0.16	0.16	0.16	0.17	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.2	3.1	3.1	3.1	3.2	3.2	3.2	3.1	3.1	3.1	3.2	3.2	3.2	3.1	3.1	3.1	3.2	2.6	2.6	2.5	2.6	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	7	6	7	7	7	7	7	6	7	7	7	7	7	6	7	7	7	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.9	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.9	0.8	0.8	0.7	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	2.8	2.8	2.6	2.6	2.6	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0500	0.0461	0.0466	0.0467	0.0498	0.0500	0.0500	0.0461	0.0470	0.0467	0.0498	0.0500	0.0500	0.0461	0.0476	0.0467	0.0498	0.0003	0.0003	0.0014	0.0012	0.0013	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0002	0.0002	0.0005	0.0003	0.0005	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.025	0.035	0.033	0.032	0.025	0.025	0.025	0.035	0.031	0.032	0.025	0.025	0.025	0.035	0.028	0.032	0.025	0.013	0.013	0.024	0.014	0.021	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0050	0.0046	0.0047	0.0047	0.0050	0.0050	0.0050	0.0046	0.0047	0.0047	0.0050	0.0050	0.0050	0.0046	0.0048	0.0047	0.0050	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.006	0.027	0.022	0.025	0.006	0.006	0.006	0.027	0.019	0.025	0.006	0.006	0.006	0.027	0.014	0.025	0.006	0.008	0.008	0.028	0.010	0.026	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.4	1.4	1.3	1.4	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.050	0.046	0.046	0.046	0.050	0.050	0.050	0.046	0.047	0.046	0.050	0.050	0.050	0.046	0.048	0.046	0.050	0.005	0.005	0.005	0.006	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0005	0.0016	0.0006	0.0014	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.008	0.007	0.008	0.008	0.008	0.007	0.008	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0001	0.0001	0.0004	0.0002	0.0004	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	9	8	9	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.100	0.092	0.093	0.093	0.100	0.100	0.100	0.092	0.094	0.093	0.100	0.100	0.100	0.092	0.095	0.093	0.100	0.002	0.002	0.004	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-7 Water Quality Results From Mine Area 2,000 m Downstream of Clarification Pond Outlets (continued)

Torotorofotsy River 2,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	33	30	30	31	33	33	33	30	31	31	33	33	33	30	31	31	33	45	45	41	43	41	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.18	0.16	0.16	0.16	0.17	0.18	0.18	0.16	0.16	0.16	0.17	0.18	0.18	0.16	0.16	0.16	0.17	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.2	3.1	3.1	3.1	3.2	3.2	3.2	3.1	3.1	3.1	3.2	3.2	3.2	3.1	3.1	3.1	3.2	2.6	2.6	2.5	2.6	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	7	7	6	7	7	7	7	7	6	7	7	7	7	7	6	7	7	7	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.9	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.9	0.8	0.8	0.7	0.7	0.8	
Sodium (Na)	mg/L	-	-	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	2.8	2.8	2.6	2.6	2.6	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0500	0.0461	0.0466	0.0467	0.0498	0.0500	0.0500	0.0461	0.0470	0.0467	0.0498	0.0500	0.0500	0.0461	0.0476	0.0467	0.0498	0.0003	0.0003	0.0014	0.0012	0.0013	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0002	0.0002	0.0005	0.0003	0.0005	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.025	0.035	0.033	0.032	0.025	0.025	0.025	0.035	0.031	0.032	0.025	0.025	0.025	0.035	0.028	0.032	0.025	0.013	0.013	0.024	0.014	0.021	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0050	0.0046	0.0047	0.0047	0.0050	0.0050	0.0050	0.0046	0.0047	0.0047	0.0050	0.0050	0.0050	0.0046	0.0048	0.0047	0.0050	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.006	0.027	0.022	0.025	0.006	0.006	0.006	0.027	0.019	0.025	0.006	0.006	0.006	0.027	0.014	0.025	0.006	0.008	0.008	0.028	0.010	0.026	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.4	1.4	1.3	1.4	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.050	0.046	0.046	0.046	0.050	0.050	0.050	0.046	0.047	0.046	0.050	0.050	0.050	0.046	0.048	0.046	0.050	0.005	0.005	0.005	0.006	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0005	0.0016	0.0006	0.0014	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.008	0.007	0.008	0.008	0.008	0.007	0.008	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0001	0.0001	0.0004	0.0002	0.0004	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	9	8	9	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.100	0.092	0.093	0.093	0.100	0.100	0.100	0.092	0.094	0.093	0.100	0.100	0.100	0.092	0.095	0.093	0.100	0.002	0.002	0.004	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-7 Water Quality Results From Mine Area 2,000 m Downstream of Clarification Pond Outlets (continued)

Ankaja River 2,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	28	28	28	28	31	33	28	28	29	28	31	33	28	28	29	28	31	45	38	38	41	38	43
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.15	0.15	0.15	0.15	0.17	0.18	0.15	0.15	0.15	0.15	0.17	0.18	0.15	0.15	0.15	0.15	0.17	0.05	0.04	0.04	0.05	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.6	1.5	1.5	1.5	1.5	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.04	0.05	0.04	0.05	0.05	0.05	0.04	0.05	0.04	0.05	0.05	0.05	0.04	0.05	0.04	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	2.9	2.9	2.9	2.9	3.1	3.2	2.9	2.9	2.9	2.9	3.1	3.2	2.9	2.9	2.9	2.9	3.1	2.6	2.4	2.4	2.4	2.4	2.5
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	7	6	6	6	6	7	7	6	6	6	6	7	7	6	6	6	6	7	8	7	7	8	7	8
Potassium (K)	mg/L	-	-	0.9	0.8	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.8	0.8	0.9	0.8	0.7	0.7	0.7	0.7	0.7
Sodium (Na)	mg/L	-	-	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.2	1.2	1.2	1.2	1.2	2.8	2.5	2.4	2.5	2.4	2.6
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2	2	1	1	2	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0431	0.0428	0.0435	0.0431	0.0479	0.0500	0.0431	0.0432	0.0437	0.0431	0.0479	0.0500	0.0431	0.0432	0.0440	0.0431	0.0479	0.0003	0.0017	0.0017	0.0015	0.0018	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0050	0.0050	0.0050	0.0050	0.0052	0.0055	0.0050	0.0050	0.0050	0.0050	0.0052	0.0055	0.0050	0.0050	0.0050	0.0050	0.0052	0.0002	0.0006	0.0005	0.0003	0.0006	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.035	0.036	0.034	0.035	0.024	0.025	0.035	0.034	0.033	0.035	0.024	0.025	0.035	0.034	0.032	0.035	0.024	0.013	0.025	0.024	0.012	0.025	0.012
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006	0.006	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0043	0.0043	0.0043	0.0043	0.0048	0.0050	0.0043	0.0043	0.0044	0.0043	0.0048	0.0050	0.0043	0.0043	0.0044	0.0043	0.0048	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.033	0.030	0.031	0.033	0.006	0.006	0.033	0.027	0.028	0.033	0.006	0.006	0.033	0.027	0.025	0.033	0.006	0.008	0.034	0.028	0.007	0.035	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.002	0.001	0.001	0.002	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.0	1.0	1.0	1.1	1.4	1.2	1.2	1.3	1.2	1.3
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.043	0.043	0.043	0.043	0.048	0.050	0.043	0.043	0.043	0.043	0.048	0.050	0.043	0.043	0.044	0.043	0.048	0.005	0.005	0.005	0.006	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0018	0.0016	0.0005	0.0018	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0046	0.0046	0.0046	0.0046	0.0048	0.0050	0.0046	0.0046	0.0046	0.0046	0.0048	0.0050	0.0046	0.0046	0.0046	0.0046	0.0048	0.0001	0.0005	0.0005	0.0002	0.0005	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	8	8	8	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.086	0.086	0.087	0.086	0.096	0.100	0.086	0.086	0.087	0.086	0.096	0.100	0.086	0.086	0.088	0.086	0.096	0.002	0.005	0.005	0.004	0.005	0.002
Vanadium (V)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.012	0.012	0.012	0.012	0.013	0.014	0.012	0.012	0.012	0.012	0.013	0.014	0.012	0.012	0.012	0.012	0.013	0.003	0.003	0.003	0.002	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-7 Water Quality Results From Mine Area 2,000 m Downstream of Clarification Pond Outlets (continued)

Antsahalava River 2,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	34	31	34	33	44	45	34	31	34	33	44	45	34	31	34	33	44	45	34	31	34	33	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.03	0.04	0.04	0.05	0.05	0.04	0.03	0.04	0.04	0.05	0.05	0.04	0.03	0.04	0.04	0.05	0.05	0.04	0.03	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4
Chloride (Cl)	mg/L	-	-	2.6	2.4	2.3	2.4	2.4	2.6	2.6	2.4	2.3	2.4	2.4	2.6	2.6	2.4	2.3	2.4	2.4	2.6	2.6	2.4	2.3	2.4	2.4	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	6	6	6	6	8	8	6	6	6	6	8	8	6	6	6	6	8	8	6	6	6	6	8
Potassium (K)	mg/L	-	-	0.8	0.6	0.5	0.6	0.6	0.8	0.8	0.6	0.5	0.6	0.6	0.8	0.8	0.6	0.5	0.6	0.6	0.8	0.8	0.6	0.5	0.6	0.6	0.8
Sodium (Na)	mg/L	-	-	2.8	2.8	3.0	2.9	2.9	2.7	2.8	2.8	3.0	2.9	2.9	2.7	2.8	2.8	3.0	2.9	2.9	2.7	2.8	2.8	3.0	2.9	2.9	2.7
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0022	0.0025	0.0023	0.0024	0.0003	0.0003	0.0022	0.0025	0.0023	0.0024	0.0003	0.0003	0.0022	0.0025	0.0023	0.0024	0.0003	0.0003	0.0022	0.0025	0.0023	0.0024	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0011	0.0015	0.0012	0.0013	0.0002	0.0002	0.0011	0.0015	0.0012	0.0013	0.0002	0.0002	0.0011	0.0015	0.0012	0.0013	0.0002	0.0002	0.0011	0.0015	0.0012	0.0013	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.060	0.081	0.063	0.069	0.013	0.013	0.060	0.081	0.063	0.069	0.013	0.013	0.060	0.081	0.063	0.069	0.013	0.013	0.060	0.081	0.063	0.069	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.020	0.020	0.019	0.020	0.008	0.008	0.020	0.020	0.019	0.020	0.008	0.008	0.020	0.020	0.019	0.020	0.008	0.008	0.020	0.020	0.019	0.020	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.1	1.0	1.1	1.0	1.4	1.4	1.1	1.0	1.1	1.0	1.4	1.4	1.1	1.0	1.1	1.0	1.4	1.4	1.1	1.0	1.1	1.0	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0041	0.0055	0.0042	0.0047	0.0005	0.0005	0.0041	0.0055	0.0042	0.0047	0.0005	0.0005	0.0041	0.0055	0.0042	0.0047	0.0005	0.0005	0.0041	0.0055	0.0042	0.0047	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0011	0.0014	0.0011	0.0012	0.0001	0.0001	0.0011	0.0014	0.0011	0.0012	0.0001	0.0001	0.0011	0.0014	0.0011	0.0012	0.0001	0.0001	0.0011	0.0014	0.0011	0.0012	0.0001
Silicon (Si)	mg/L	-	-	9	7	6	7	7	9	9	7	6	7	7	9	9	7	6	7	7	9	9	7	6	7	7	9
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.007	0.006	0.006	0.004	0.005	0.006	0.007	0.006	0.006	0.004	0.005	0.006	0.007	0.006	0.006	0.004	0.005	0.006	0.007	0.006	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.005	0.006	0.006	0.006	0.002	0.002	0.005	0.006	0.006	0.006	0.002	0.002	0.005	0.006	0.006	0.006	0.002	0.002	0.005	0.006	0.006	0.006	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.004	0.005	0.004	0.005	0.002	0.003	0.004	0.005	0.004	0.005	0.002	0.003	0.004	0.005	0.004	0.005	0.002	0.003	0.004	0.005	0.004	0.005	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-7 Water Quality Results From Mine Area 2,000 m Downstream of Clarification Pond Outlets (continued)

Sahaviara River 2,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	37	37	34	36	44	45	37	37	34	36	44	45	37	37	34	36	44	45	37	37	34	36	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.6	1.6	1.6	1.6	1.5	1.5	1.6	1.6	1.6	1.6	1.5	1.5	1.6	1.6	1.6	1.6	1.5	1.5	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	3	3	4	4	4	4	3	3	4	4	4	4	3	3	4	4	4	4	3	3	4
Chloride (Cl)	mg/L	-	-	2.6	2.3	2.3	2.3	2.3	2.6	2.6	2.3	2.3	2.3	2.3	2.6	2.6	2.3	2.3	2.3	2.3	2.6	2.6	2.3	2.3	2.3	2.3	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	7	6	7	8	8	7	7	6	7	8	8	7	7	6	7	8	8	7	7	6	7	8
Potassium (K)	mg/L	-	-	0.8	0.6	0.6	0.6	0.6	0.7	0.8	0.6	0.6	0.6	0.6	0.7	0.8	0.6	0.6	0.6	0.6	0.7	0.8	0.6	0.6	0.6	0.6	0.7
Sodium (Na)	mg/L	-	-	2.8	2.6	2.7	2.8	2.7	2.7	2.8	2.6	2.7	2.8	2.7	2.7	2.8	2.6	2.7	2.8	2.7	2.7	2.8	2.6	2.7	2.8	2.7	2.7
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0013	0.0012	0.0015	0.0013	0.0003	0.0003	0.0013	0.0012	0.0015	0.0013	0.0003	0.0003	0.0013	0.0012	0.0015	0.0013	0.0003	0.0003	0.0013	0.0012	0.0015	0.0013	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0007	0.0006	0.0010	0.0008	0.0002	0.0002	0.0007	0.0006	0.0010	0.0008	0.0002	0.0002	0.0007	0.0006	0.0010	0.0008	0.0002	0.0002	0.0007	0.0006	0.0010	0.0008	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.038	0.037	0.059	0.047	0.013	0.013	0.038	0.037	0.059	0.047	0.013	0.013	0.038	0.037	0.059	0.047	0.013	0.013	0.038	0.037	0.059	0.047	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.012	0.012	0.013	0.013	0.008	0.008	0.012	0.012	0.013	0.013	0.008	0.008	0.012	0.012	0.013	0.013	0.008	0.008	0.012	0.012	0.013	0.013	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.1	1.1	1.0	1.1	1.4	1.4	1.1	1.1	1.0	1.1	1.4	1.4	1.1	1.1	1.0	1.1	1.4	1.4	1.1	1.1	1.0	1.1	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0023	0.0023	0.0038	0.0030	0.0005	0.0005	0.0023	0.0023	0.0038	0.0030	0.0005	0.0005	0.0023	0.0023	0.0038	0.0030	0.0005	0.0005	0.0023	0.0023	0.0038	0.0030	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.006	0.006	0.008	0.008	0.007	0.007	0.006	0.006	0.008	0.008	0.007	0.007	0.006	0.006	0.008	0.008	0.007	0.007	0.006	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0006	0.0006	0.0010	0.0007	0.0001	0.0001	0.0006	0.0006	0.0010	0.0007	0.0001	0.0001	0.0006	0.0006	0.0010	0.0007	0.0001	0.0001	0.0006	0.0006	0.0010	0.0007	0.0001
Silicon (Si)	mg/L	-	-	9	7	7	7	7	9	9	7	7	7	7	9	9	7	7	7	7	9	9	7	7	7	7	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.004	0.004	0.002	0.003	0.003	0.003	0.004	0.004	0.002	0.003	0.003	0.003	0.004	0.004	0.002	0.003	0.003	0.003	0.004	0.004	0.002

Notes

1 World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2 Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3 Based on the un-ionized portion of ammonia.

4 Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5 Based on long-term exposure.

6 Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7 Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8 Based on an alkalinity value of less than 60 mg/L.

9 Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10 Based on the dissolved form of this metal.

11 Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12 Based on a dissolved saturation of at least 80%.

13 Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-7 Water Quality Results From Mine Area 2,000 m Downstream of Clarification Pond Outlets (continued)

Sahamarirana River 2,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	35	35	37	37	42	45	35	35	37	37	42	45	35	35	37	37	42	45	35	35	37	37	42
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.5	1.5	1.5	1.6	1.5	1.5	1.5	1.5	1.5	1.6	1.5	1.5	1.5	1.5	1.5	1.6	1.5	1.5	1.5	1.5	1.5
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	3	3	4	4	4	4	3	3	4	4	4	4	3	3	4	4	4	4	3	3	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.3	2.3	2.3	2.3	2.5	2.6	2.3	2.3	2.3	2.3	2.5	2.6	2.3	2.3	2.3	2.3	2.5	2.6	2.3	2.3	2.3	2.3	2.5
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	7	7	7	8	8	7	7	7	7	8	8	7	7	7	7	8	8	7	7	7	7	8
Potassium (K)	mg/L	-	-	0.8	0.6	0.6	0.6	0.6	0.7	0.8	0.6	0.6	0.6	0.6	0.7	0.8	0.6	0.6	0.6	0.6	0.7	0.8	0.6	0.6	0.6	0.6	0.7
Sodium (Na)	mg/L	-	-	2.8	2.6	2.6	2.5	2.5	2.6	2.8	2.6	2.6	2.5	2.5	2.6	2.8	2.6	2.6	2.5	2.5	2.6	2.8	2.6	2.6	2.5	2.5	2.6
Sulphate (SO ₄)	mg/L	-	-	1	2	2	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0016	0.0016	0.0012	0.0012	0.0003	0.0003	0.0016	0.0016	0.0012	0.0012	0.0003	0.0003	0.0016	0.0016	0.0012	0.0012	0.0003	0.0003	0.0016	0.0016	0.0012	0.0012	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0007	0.0007	0.0004	0.0005	0.0002	0.0002	0.0007	0.0007	0.0004	0.0005	0.0002	0.0002	0.0007	0.0007	0.0004	0.0005	0.0002	0.0002	0.0007	0.0007	0.0004	0.0005	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.038	0.039	0.024	0.026	0.012	0.013	0.038	0.039	0.024	0.026	0.012	0.013	0.038	0.039	0.024	0.026	0.012	0.013	0.038	0.039	0.024	0.026	0.012
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.017	0.017	0.011	0.009	0.007	0.008	0.017	0.017	0.011	0.009	0.007	0.008	0.017	0.017	0.011	0.009	0.007	0.008	0.017	0.017	0.011	0.009	0.007
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Iron (Fe)	mg/L	-	-	1.4	1.1	1.1	1.2	1.2	1.3	1.4	1.1	1.1	1.2	1.2	1.3	1.4	1.1	1.1	1.2	1.2	1.3	1.4	1.1	1.1	1.2	1.2	1.3
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0025	0.0026	0.0014	0.0014	0.0005	0.0005	0.0025	0.0026	0.0014	0.0014	0.0005	0.0005	0.0025	0.0026	0.0014	0.0014	0.0005	0.0005	0.0025	0.0026	0.0014	0.0014	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.007	0.007	0.007	0.008	0.006	0.006	0.007	0.007	0.007	0.008	0.006	0.006	0.007	0.007	0.007	0.008	0.006	0.006	0.007	0.007	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0007	0.0007	0.0004	0.0004	0.0001	0.0001	0.0007	0.0007	0.0004	0.0004	0.0001	0.0001	0.0007	0.0007	0.0004	0.0004	0.0001	0.0001	0.0007	0.0007	0.0004	0.0004	0.0001
Silicon (Si)	mg/L	-	-	9	7	7	8	8	9	9	7	7	8	8	9	9	7	7	8	8	9	9	7	7	8	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-7 Water Quality Results From Mine Area 2,000 m Downstream of Clarification Pond Outlets (continued)

Torotorofotsy River 2,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	41	43	41	44	45	45	41	43	41	44	45	45	41	43	41	44	45	45	41	43	41	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.5	2.6	2.5	2.6	2.6	2.6	2.5	2.6	2.5	2.6	2.6	2.6	2.5	2.6	2.5	2.6	2.6	2.6	2.5	2.6	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	2.8	2.8	2.6	2.6	2.6	2.7	2.8	2.8	2.6	2.6	2.6	2.7	2.8	2.8	2.6	2.6	2.6	2.7	2.8	2.8	2.6	2.6	2.6	2.7
Sulphate (SO ₄)	mg/L	-	-	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0014	0.0012	0.0013	0.0003	0.0003	0.0003	0.0014	0.0012	0.0013	0.0003	0.0003	0.0003	0.0014	0.0012	0.0013	0.0003	0.0003	0.0003	0.0014	0.0012	0.0013	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0005	0.0003	0.0005	0.0002	0.0002	0.0002	0.0005	0.0003	0.0005	0.0002	0.0002	0.0002	0.0005	0.0003	0.0005	0.0002	0.0002	0.0002	0.0005	0.0003	0.0005	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.024	0.014	0.021	0.013	0.013	0.013	0.024	0.014	0.021	0.013	0.013	0.013	0.024	0.014	0.021	0.013	0.013	0.013	0.024	0.014	0.021	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.028	0.010	0.026	0.008	0.008	0.008	0.028	0.010	0.026	0.008	0.008	0.008	0.028	0.010	0.026	0.008	0.008	0.008	0.028	0.010	0.026	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0016	0.0006	0.0014	0.0005	0.0005	0.0005	0.0016	0.0006	0.0014	0.0005	0.0005	0.0005	0.0016	0.0006	0.0014	0.0005	0.0005	0.0005	0.0016	0.0006	0.0014	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0004	0.0002	0.0004	0.0001	0.0001	0.0001	0.0004	0.0002	0.0004	0.0001	0.0001	0.0001	0.0004	0.0002	0.0004	0.0001	0.0001	0.0001	0.0004	0.0002	0.0004	0.0001
Silicon (Si)	mg/L	-	-	9	9	8	9	8	9	9	9	8	9	8	9	9	9	8	9	8	9	9	9	8	9	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.004	0.004	0.004	0.002	0.002	0.002	0.004	0.004	0.004	0.002	0.002	0.002	0.004	0.004	0.004	0.002	0.002	0.002	0.004	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-7 Water Quality Results From Mine Area 2,000 m Downstream of Clarification Pond Outlets (continued)

Sakalava River 2,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	42	39	42	44	45	45	42	39	42	44	45	45	42	39	42	44	45	45	42	39	42	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.5	2.5	2.5	2.6	2.6	2.6	2.5	2.5	2.5	2.6	2.6	2.6	2.5	2.5	2.5	2.6	2.6	2.6	2.5	2.5	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	7	8	8	8	8	8	7	8	8	8	8	8	7	8	8	8	8	8	7	8	8
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7
Sodium (Na)	mg/L	-	-	2.8	2.8	2.6	2.5	2.6	2.7	2.8	2.8	2.6	2.5	2.6	2.7	2.8	2.8	2.6	2.5	2.6	2.7	2.8	2.8	2.6	2.5	2.6	2.7
Sulphate (SO ₄)	mg/L	-	-	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0016	0.0016	0.0013	0.0003	0.0003	0.0003	0.0016	0.0016	0.0013	0.0003	0.0003	0.0003	0.0016	0.0016	0.0013	0.0003	0.0003	0.0003	0.0016	0.0016	0.0013	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0003	0.0006	0.0003	0.0002	0.0002	0.0002	0.0003	0.0006	0.0003	0.0002	0.0002	0.0002	0.0003	0.0006	0.0003	0.0002	0.0002	0.0002	0.0003	0.0006	0.0003	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.013	0.027	0.013	0.013	0.013	0.013	0.013	0.027	0.013	0.013	0.013	0.013	0.013	0.027	0.013	0.013	0.013	0.013	0.013	0.027	0.013	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.008	0.038	0.009	0.008	0.008	0.008	0.008	0.038	0.009	0.008	0.008	0.008	0.008	0.038	0.009	0.008	0.008	0.008	0.008	0.038	0.009	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0005	0.0020	0.0005	0.0005	0.0005	0.0005	0.0005	0.0020	0.0005	0.0005	0.0005	0.0005	0.0005	0.0020	0.0005	0.0005	0.0005	0.0005	0.0005	0.0020	0.0005	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0002	0.0005	0.0002	0.0001	0.0001	0.0001	0.0002	0.0005	0.0002	0.0001	0.0001	0.0001	0.0002	0.0005	0.0002	0.0001	0.0001	0.0001	0.0002	0.0005	0.0002	0.0001
Silicon (Si)	mg/L	-	-	9	9	9	8	9	9	9	9	9	8	9	9	9	9	9	8	9	9	9	9	9	8	9	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.005	0.004	0.004	0.002	0.002	0.002	0.005	0.004	0.004	0.002	0.002	0.002	0.005	0.004	0.004	0.002	0.002	0.002	0.005	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-7 Water Quality Results From Mine Area 2,000 m Downstream of Clarification Pond Outlets (continued)

Ankaja River 2,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	38	38	41	38	43	45	38	38	41	38	43	45	38	38	41	38	43	45	38	38	41	38	43
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.4	2.4	2.4	2.4	2.5	2.6	2.4	2.4	2.4	2.4	2.5	2.6	2.4	2.4	2.4	2.4	2.5	2.6	2.4	2.4	2.4	2.4	2.5
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	7	8	7	8	8	7	7	8	7	8	8	7	7	8	7	8	8	7	7	8	7	8
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7
Sodium (Na)	mg/L	-	-	2.8	2.5	2.4	2.5	2.4	2.6	2.8	2.5	2.4	2.5	2.4	2.6	2.8	2.5	2.4	2.5	2.4	2.6	2.8	2.5	2.4	2.5	2.4	2.6
Sulphate (SO ₄)	mg/L	-	-	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0017	0.0017	0.0015	0.0018	0.0003	0.0003	0.0017	0.0017	0.0015	0.0018	0.0003	0.0003	0.0017	0.0017	0.0015	0.0018	0.0003	0.0003	0.0017	0.0017	0.0015	0.0018	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0006	0.0005	0.0003	0.0006	0.0002	0.0002	0.0006	0.0005	0.0003	0.0006	0.0002	0.0002	0.0006	0.0005	0.0003	0.0006	0.0002	0.0002	0.0006	0.0005	0.0003	0.0006	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.025	0.024	0.012	0.025	0.012	0.013	0.025	0.024	0.012	0.025	0.012	0.013	0.025	0.024	0.012	0.025	0.012	0.013	0.025	0.024	0.012	0.025	0.012
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.034	0.028	0.007	0.035	0.008	0.008	0.034	0.028	0.007	0.035	0.008	0.008	0.034	0.028	0.007	0.035	0.008	0.008	0.034	0.028	0.007	0.035	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.2	1.2	1.3	1.2	1.3	1.4	1.2	1.2	1.3	1.2	1.3	1.4	1.2	1.2	1.3	1.2	1.3	1.4	1.2	1.2	1.3	1.2	1.3
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0018	0.0016	0.0005	0.0018	0.0005	0.0005	0.0018	0.0016	0.0005	0.0018	0.0005	0.0005	0.0018	0.0016	0.0005	0.0018	0.0005	0.0005	0.0018	0.0016	0.0005	0.0018	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0005	0.0005	0.0002	0.0005	0.0001	0.0001	0.0005	0.0005	0.0002	0.0005	0.0001	0.0001	0.0005	0.0005	0.0002	0.0005	0.0001	0.0001	0.0005	0.0005	0.0002	0.0005	0.0001
Silicon (Si)	mg/L	-	-	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.006	0.004	0.005	0.005	0.005	0.005	0.006	0.004	0.005	0.005	0.005	0.005	0.006	0.004	0.005	0.005	0.005	0.005	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.005	0.005	0.004	0.005	0.002	0.002	0.005	0.005	0.004	0.005	0.002	0.002	0.005	0.005	0.004	0.005	0.002	0.002	0.005	0.005	0.004	0.005	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-7 Water Quality Results From Mine Area 2,000 m Downstream of Clarification Pond Outlets (continued)

Antsahalava River 2,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	34	31	34	33	44	45	34	31	34	33	44	45	34	31	34	33	44	33	26	23	25	24	33
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.03	0.04	0.04	0.05	0.05	0.04	0.03	0.04	0.04	0.05	0.05	0.04	0.03	0.04	0.04	0.05	0.18	0.13	0.12	0.13	0.12	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.4	1.4	1.5	1.5	1.5	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.04	0.04	0.04	0.04	0.05
Calcium (Ca)	mg/L	-	-	4	3	3	3	3	4	4	3	3	3	3	4	4	3	3	3	3	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.4	2.3	2.4	2.4	2.6	2.6	2.4	2.3	2.4	2.4	2.6	2.6	2.4	2.3	2.4	2.4	2.6	3.2	2.8	2.7	2.8	2.7	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	6	6	6	6	8	8	6	6	6	6	8	8	6	6	6	6	8	7	5	5	5	5	7
Potassium (K)	mg/L	-	-	0.8	0.6	0.5	0.6	0.6	0.8	0.8	0.6	0.5	0.6	0.6	0.8	0.8	0.6	0.5	0.6	0.6	0.8	0.9	0.7	0.6	0.7	0.7	0.9
Sodium (Na)	mg/L	-	-	2.8	2.8	3.0	2.9	2.9	2.7	2.8	2.8	3.0	2.9	2.9	2.7	2.8	2.8	3.0	2.9	2.9	2.7	1.3	1.8	2.0	1.8	1.9	1.3
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0022	0.0025	0.0023	0.0024	0.0003	0.0003	0.0022	0.0025	0.0023	0.0024	0.0003	0.0003	0.0022	0.0025	0.0023	0.0024	0.0003	0.0500	0.0388	0.0351	0.0382	0.0367	0.0497
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0011	0.0015	0.0012	0.0013	0.0002	0.0002	0.0011	0.0015	0.0012	0.0013	0.0002	0.0002	0.0011	0.0015	0.0012	0.0013	0.0002	0.0055	0.0050	0.0050	0.0050	0.0050	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.060	0.081	0.063	0.069	0.013	0.013	0.060	0.081	0.063	0.069	0.013	0.013	0.060	0.081	0.063	0.069	0.013	0.025	0.069	0.092	0.073	0.081	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.007	0.006	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0050	0.0039	0.0035	0.0038	0.0037	0.0050
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.020	0.020	0.019	0.020	0.008	0.008	0.020	0.020	0.019	0.020	0.008	0.008	0.020	0.020	0.019	0.020	0.008	0.006	0.019	0.020	0.019	0.019	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.005	0.004	0.003	0.004	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.003	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.1	1.0	1.1	1.0	1.4	1.4	1.1	1.0	1.1	1.0	1.4	1.4	1.1	1.0	1.1	1.0	1.4	1.1	0.9	0.8	0.9	0.8	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.050	0.038	0.034	0.037	0.036	0.050
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.07	0.06	0.05	0.05	0.05	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001	0.0002	0.0002	0.0002	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0041	0.0055	0.0042	0.0047	0.0005	0.0005	0.0041	0.0055	0.0042	0.0047	0.0005	0.0005	0.0041	0.0055	0.0042	0.0047	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008	0.008	0.006	0.006	0.006	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0011	0.0014	0.0011	0.0012	0.0001	0.0001	0.0011	0.0014	0.0011	0.0012	0.0001	0.0001	0.0011	0.0014	0.0011	0.0012	0.0001	0.0050	0.0047	0.0047	0.0047	0.0047	0.0050
Silicon (Si)	mg/L	-	-	9	7	6	7	7	9	9	7	6	7	7	9	9	7	6	7	7	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.007	0.006	0.006	0.004	0.005	0.006	0.007	0.006	0.006	0.004	0.005	0.006	0.007	0.006	0.006	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.005	0.006	0.006	0.006	0.002	0.002	0.005	0.006	0.006	0.006	0.002	0.002	0.005	0.006	0.006	0.006	0.002	0.100	0.078	0.070	0.076	0.073	0.099
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.004	0.004	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.004	0.005	0.004	0.005	0.002	0.003	0.004	0.005	0.004	0.005	0.002	0.003	0.004	0.005	0.004	0.005	0.002	0.014	0.013	0.013	0.013	0.013	0.014

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-7 Water Quality Results From Mine Area 2,000 m Downstream of Clarification Pond Outlets (continued)

Sahaviara River 2,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	37	37	34	36	44	45	37	37	34	36	44	45	37	37	34	35	44	33	27	27	24	25	32
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.18	0.14	0.14	0.12	0.13	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.6	1.6	1.6	1.6	1.5	1.5	1.6	1.6	1.6	1.6	1.5	1.5	1.6	1.6	1.6	1.4	1.3	1.3	1.4	1.4	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.04	0.04	0.04	0.04	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	3	3	4	4	4	4	3	3	4	4	4	4	3	3	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.3	2.3	2.3	2.3	2.6	2.6	2.3	2.3	2.3	2.3	2.6	2.6	2.3	2.3	2.3	2.3	2.6	3.2	2.8	2.8	2.7	2.7	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	7	6	7	8	8	7	7	6	7	8	8	7	7	6	7	8	7	6	6	5	5	7
Potassium (K)	mg/L	-	-	0.8	0.6	0.6	0.6	0.6	0.7	0.8	0.6	0.6	0.6	0.6	0.7	0.8	0.6	0.6	0.6	0.6	0.7	0.9	0.7	0.7	0.7	0.7	0.9
Sodium (Na)	mg/L	-	-	2.8	2.6	2.7	2.8	2.7	2.7	2.8	2.6	2.7	2.8	2.7	2.7	2.8	2.6	2.7	2.8	2.7	2.7	1.3	1.5	1.5	1.8	1.6	1.3
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0013	0.0012	0.0015	0.0013	0.0003	0.0003	0.0013	0.0012	0.0015	0.0013	0.0003	0.0003	0.0013	0.0012	0.0015	0.0013	0.0003	0.0500	0.0412	0.0405	0.0367	0.0384	0.0493
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0007	0.0006	0.0010	0.0008	0.0002	0.0002	0.0007	0.0006	0.0010	0.0008	0.0002	0.0002	0.0007	0.0006	0.0010	0.0008	0.0002	0.0055	0.0049	0.0049	0.0048	0.0048	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.038	0.037	0.059	0.047	0.013	0.013	0.038	0.037	0.059	0.047	0.013	0.013	0.038	0.037	0.060	0.049	0.013	0.025	0.047	0.049	0.073	0.062	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.006	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0041	0.0041	0.0037	0.0038	0.0049
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.012	0.012	0.013	0.013	0.008	0.008	0.012	0.012	0.013	0.013	0.008	0.008	0.012	0.012	0.013	0.013	0.008	0.006	0.011	0.011	0.013	0.012	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.005	0.004	0.004	0.004	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.1	1.1	1.0	1.1	1.4	1.4	1.1	1.1	1.0	1.1	1.4	1.4	1.1	1.1	1.0	1.1	1.4	1.1	0.9	0.9	0.8	0.9	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.050	0.041	0.040	0.036	0.038	0.049
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.07	0.06	0.06	0.05	0.05	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001	0.0002	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0023	0.0023	0.0038	0.0030	0.0005	0.0005	0.0023	0.0023	0.0038	0.0030	0.0005	0.0005	0.0023	0.0023	0.0038	0.0031	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.006	0.006	0.008	0.008	0.007	0.007	0.006	0.006	0.008	0.008	0.007	0.007	0.006	0.006	0.008	0.008	0.007	0.007	0.006	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0006	0.0006	0.0010	0.0007	0.0001	0.0001	0.0006	0.0006	0.0010	0.0007	0.0001	0.0001	0.0006	0.0006	0.0010	0.0008	0.0001	0.0050	0.0046	0.0045	0.0045	0.0045	0.0049
Silicon (Si)	mg/L	-	-	9	7	7	7	7	9	9	7	7	7	7	9	9	7	7	7	7	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.100	0.082	0.081	0.073	0.077	0.099
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.004	0.004	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.004	0.004	0.002	0.003	0.003	0.003	0.004	0.004	0.002	0.003	0.003	0.003	0.004	0.004	0.002	0.014	0.012	0.012	0.012	0.012	0.014

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-7 Water Quality Results From Mine Area 2,000 m Downstream of Clarification Pond Outlets (continued)

Sahamarirana River 2,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	35	35	37	37	42	45	35	35	37	37	42	45	35	35	37	37	42	33	26	25	27	27	31
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.18	0.13	0.13	0.14	0.14	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.5	1.5	1.5	1.6	1.5	1.5	1.5	1.5	1.5	1.6	1.5	1.5	1.5	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.3
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.04	0.04	0.04	0.04	0.05
Calcium (Ca)	mg/L	-	-	4	3	3	4	4	4	4	3	3	4	4	4	4	3	3	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.3	2.3	2.3	2.3	2.5	2.6	2.3	2.3	2.3	2.3	2.5	2.6	2.3	2.3	2.3	2.3	2.5	3.2	2.7	2.7	2.8	2.7	3.0
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	7	7	7	8	8	7	7	7	7	8	8	7	7	7	7	8	7	6	5	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.6	0.6	0.6	0.6	0.7	0.8	0.6	0.6	0.6	0.6	0.7	0.8	0.6	0.6	0.6	0.6	0.7	0.9	0.7	0.7	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	2.8	2.6	2.6	2.5	2.5	2.6	2.8	2.6	2.6	2.5	2.5	2.6	2.8	2.6	2.6	2.5	2.5	2.6	1.3	1.4	1.5	1.3	1.3	1.2
Sulphate (SO ₄)	mg/L	-	-	1	2	2	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1	2	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0016	0.0016	0.0012	0.0012	0.0003	0.0003	0.0016	0.0016	0.0012	0.0012	0.0003	0.0003	0.0016	0.0016	0.0012	0.0012	0.0003	0.0500	0.0392	0.0385	0.0415	0.0407	0.0473
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0007	0.0007	0.0004	0.0005	0.0002	0.0002	0.0007	0.0007	0.0004	0.0005	0.0002	0.0002	0.0007	0.0007	0.0004	0.0005	0.0002	0.0055	0.0047	0.0047	0.0047	0.0047	0.0052
Barium (Ba)	mg/L	0.7	-	0.013	0.038	0.039	0.024	0.026	0.012	0.013	0.038	0.039	0.024	0.026	0.012	0.013	0.038	0.039	0.024	0.026	0.012	0.025	0.047	0.050	0.034	0.037	0.024
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.006	0.006	0.006	0.006	0.006
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0039	0.0039	0.0042	0.0041	0.0047
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.017	0.017	0.011	0.009	0.007	0.008	0.017	0.017	0.011	0.009	0.007	0.008	0.017	0.017	0.011	0.009	0.007	0.006	0.016	0.016	0.010	0.008	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.005	0.004	0.004	0.004	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.1	1.1	1.2	1.2	1.3	1.4	1.1	1.1	1.2	1.2	1.3	1.4	1.1	1.1	1.2	1.2	1.3	1.1	0.9	0.9	1.0	0.9	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.039	0.038	0.041	0.040	0.047
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.07	0.06	0.06	0.06	0.06	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0025	0.0026	0.0014	0.0014	0.0005	0.0005	0.0025	0.0026	0.0014	0.0014	0.0005	0.0005	0.0025	0.0026	0.0014	0.0014	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.007	0.007	0.007	0.008	0.006	0.006	0.007	0.007	0.007	0.008	0.006	0.006	0.007	0.007	0.007	0.008	0.006	0.006	0.007	0.006	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0007	0.0007	0.0004	0.0004	0.0001	0.0001	0.0007	0.0007	0.0004	0.0004	0.0001	0.0001	0.0007	0.0007	0.0004	0.0004	0.0001	0.0050	0.0044	0.0044	0.0044	0.0043	0.0047
Silicon (Si)	mg/L	-	-	9	7	7	8	8	9	9	7	7	8	8	9	9	7	7	8	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.100	0.078	0.077	0.083	0.081	0.095
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.004	0.004	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.014	0.012	0.012	0.012	0.012	0.013

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-7 Water Quality Results From Mine Area 2,000 m Downstream of Clarification Pond Outlets (continued)

Torotorofotsy River 2,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	41	43	41	44	45	45	41	43	41	44	45	45	41	43	41	44	33	33	30	31	31	33
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.18	0.18	0.16	0.16	0.16	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.4	1.4	1.4	1.4	1.4	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.5	2.6	2.5	2.6	2.6	2.6	2.5	2.6	2.5	2.6	2.6	2.6	2.5	2.6	2.5	2.6	3.2	3.2	3.1	3.1	3.1	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7	7	6	7	7	7
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.9	0.9	0.8	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.8	2.6	2.6	2.6	2.7	2.8	2.8	2.6	2.6	2.6	2.7	2.8	2.8	2.6	2.6	2.6	2.7	1.3	1.3	1.3	1.3	1.3	1.3
Sulphate (SO ₄)	mg/L	-	-	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0014	0.0012	0.0013	0.0003	0.0003	0.0003	0.0014	0.0012	0.0013	0.0003	0.0003	0.0003	0.0014	0.0012	0.0013	0.0003	0.0500	0.0500	0.0461	0.0470	0.0467	0.0498
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0005	0.0003	0.0005	0.0002	0.0002	0.0002	0.0005	0.0003	0.0005	0.0002	0.0002	0.0002	0.0005	0.0003	0.0005	0.0002	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.024	0.014	0.021	0.013	0.013	0.013	0.024	0.014	0.021	0.013	0.013	0.013	0.024	0.014	0.021	0.013	0.025	0.025	0.035	0.031	0.032	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.007	0.007	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0050	0.0050	0.0046	0.0047	0.0047	0.0050
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.028	0.010	0.026	0.008	0.008	0.008	0.028	0.010	0.026	0.008	0.008	0.008	0.028	0.010	0.026	0.008	0.006	0.006	0.027	0.019	0.025	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.4	1.1	1.1	1.1	1.1	1.1	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.050	0.050	0.046	0.047	0.046	0.050
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0016	0.0006	0.0014	0.0005	0.0005	0.0005	0.0016	0.0006	0.0014	0.0005	0.0005	0.0005	0.0016	0.0006	0.0014	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.008	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0004	0.0002	0.0004	0.0001	0.0001	0.0001	0.0004	0.0002	0.0004	0.0001	0.0001	0.0001	0.0004	0.0002	0.0004	0.0001	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050
Silicon (Si)	mg/L	-	-	9	9	8	9	8	9	9	9	8	9	8	9	9	9	8	9	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.004	0.004	0.004	0.002	0.002	0.002	0.004	0.004	0.004	0.002	0.002	0.002	0.004	0.004	0.004	0.002	0.100	0.100	0.092	0.094	0.093	0.100
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.014	0.014	0.013	0.013	0.013	0.014

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-7 Water Quality Results From Mine Area 2,000 m Downstream of Clarification Pond Outlets (continued)

Sakalava River 2,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	42	39	42	44	45	45	42	39	42	44	45	45	42	39	42	44	33	33	30	29	30	32
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.18	0.18	0.16	0.15	0.16	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6	1.6	1.6	1.5	1.6	1.5	1.6	1.4	1.4	1.3	1.4	1.3	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.5	2.5	2.5	2.6	2.6	2.6	2.5	2.5	2.5	2.6	2.6	2.6	2.5	2.5	2.5	2.6	3.2	3.2	3.0	3.0	3.0	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	7	8	8	8	8	8	7	8	8	8	8	8	7	8	8	7	7	6	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.9	0.9	0.8	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.8	2.6	2.5	2.6	2.7	2.8	2.8	2.6	2.5	2.6	2.7	2.8	2.8	2.6	2.5	2.6	2.7	1.3	1.3	1.2	1.3	1.2	1.3
Sulphate (SO ₄)	mg/L	-	-	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0016	0.0016	0.0013	0.0003	0.0003	0.0003	0.0016	0.0016	0.0013	0.0003	0.0003	0.0003	0.0016	0.0016	0.0013	0.0003	0.0500	0.0500	0.0457	0.0441	0.0462	0.0495
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0003	0.0006	0.0003	0.0002	0.0002	0.0002	0.0003	0.0006	0.0003	0.0002	0.0002	0.0002	0.0003	0.0006	0.0003	0.0002	0.0055	0.0055	0.0052	0.0051	0.0051	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.013	0.027	0.013	0.013	0.013	0.013	0.013	0.027	0.013	0.013	0.013	0.013	0.013	0.027	0.013	0.013	0.025	0.025	0.031	0.037	0.028	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.007	0.007	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0005	0.0050	0.0050	0.0046	0.0044	0.0046	0.0049
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.008	0.038	0.009	0.008	0.008	0.008	0.008	0.038	0.009	0.008	0.008	0.008	0.008	0.038	0.009	0.008	0.006	0.006	0.022	0.037	0.015	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.004	0.005	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.005	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4	1.4	1.4	1.3	1.2	1.3	1.4	1.1	1.1	1.1	1.0	1.1	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.050	0.050	0.046	0.044	0.046	0.049
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.06	0.07	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0005	0.0004	0.0005	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0005	0.0020	0.0005	0.0005	0.0005	0.0005	0.0005	0.0020	0.0005	0.0005	0.0005	0.0005	0.0005	0.0020	0.0005	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0002	0.0005	0.0002	0.0001	0.0001	0.0001	0.0002	0.0005	0.0002	0.0001	0.0001	0.0001	0.0002	0.0005	0.0002	0.0001	0.0050	0.0050	0.0048	0.0048	0.0047	0.0049
Silicon (Si)	mg/L	-	-	9	9	9	8	9	9	9	9	9	8	9	9	9	9	9	8	9	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.005	0.004	0.004	0.002	0.002	0.002	0.005	0.004	0.004	0.002	0.002	0.002	0.005	0.004	0.004	0.002	0.100	0.100	0.091	0.088	0.092	0.099
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.004	0.005	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.014	0.014	0.013	0.013	0.013	0.014

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-7 Water Quality Results From Mine Area 2,000 m Downstream of Clarification Pond Outlets (continued)

Ankaja River 2,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	38	38	41	38	43	45	38	38	41	38	43	45	38	38	41	38	43	33	28	28	29	28	31
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05	0.18	0.15	0.15	0.15	0.15	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.4	1.3	1.3	1.3	1.3	1.3
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.04	0.05	0.04	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.4	2.4	2.4	2.4	2.5	2.6	2.4	2.4	2.4	2.4	2.5	2.6	2.4	2.4	2.4	2.4	2.5	3.2	2.9	2.9	2.9	2.9	3.1
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	7	8	7	8	8	7	7	8	7	8	8	7	7	8	7	8	7	6	6	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.9	0.8	0.8	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.5	2.4	2.5	2.4	2.6	2.8	2.5	2.4	2.5	2.4	2.6	2.8	2.5	2.4	2.5	2.4	2.6	1.3	1.2	1.2	1.2	1.2	1.2
Sulphate (SO ₄)	mg/L	-	-	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	2	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0017	0.0017	0.0015	0.0018	0.0003	0.0003	0.0017	0.0017	0.0015	0.0018	0.0003	0.0003	0.0017	0.0017	0.0016	0.0018	0.0003	0.0500	0.0431	0.0432	0.0437	0.0431	0.0479
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0006	0.0005	0.0003	0.0006	0.0002	0.0002	0.0006	0.0005	0.0003	0.0006	0.0002	0.0002	0.0006	0.0005	0.0003	0.0006	0.0002	0.0055	0.0050	0.0050	0.0050	0.0050	0.0052
Barium (Ba)	mg/L	0.7	-	0.013	0.025	0.024	0.012	0.025	0.012	0.013	0.025	0.024	0.012	0.025	0.012	0.013	0.025	0.024	0.012	0.025	0.012	0.025	0.035	0.034	0.033	0.035	0.024
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.006	0.006	0.006	0.006	0.006
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0050	0.0043	0.0043	0.0044	0.0043	0.0048
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.034	0.028	0.007	0.035	0.008	0.008	0.034	0.028	0.007	0.035	0.008	0.008	0.034	0.028	0.008	0.035	0.008	0.006	0.033	0.027	0.028	0.033	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.005	0.004	0.004	0.004	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.2	1.2	1.3	1.2	1.3	1.4	1.2	1.2	1.3	1.2	1.3	1.4	1.2	1.2	1.3	1.2	1.3	1.1	1.0	1.0	1.0	1.0	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.050	0.043	0.043	0.043	0.043	0.048
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0018	0.0016	0.0005	0.0018	0.0005	0.0005	0.0018	0.0016	0.0005	0.0018	0.0005	0.0005	0.0018	0.0016	0.0005	0.0018	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0005	0.0005	0.0002	0.0005	0.0001	0.0001	0.0005	0.0005	0.0002	0.0005	0.0001	0.0001	0.0005	0.0005	0.0002	0.0005	0.0001	0.0050	0.0046	0.0046	0.0046	0.0046	0.0048
Silicon (Si)	mg/L	-	-	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.006	0.004	0.005	0.005	0.005	0.005	0.006	0.004	0.005	0.005	0.005	0.005	0.006	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.005	0.005	0.004	0.005	0.002	0.002	0.005	0.005	0.004	0.005	0.002	0.002	0.005	0.005	0.004	0.005	0.002	0.100	0.086	0.086	0.087	0.086	0.096
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.004	0.004	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.014	0.012	0.012	0.012	0.012	0.013

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-8 Water Quality Results From Mine Area 3,000 m Downstream of Clarification Pond Outlets

Antsahalava River 3,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	27	25	27	26	33	33	27	25	27	26	33	33	27	25	27	26	33	45	36	34	36	36	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.14	0.13	0.14	0.13	0.17	0.18	0.14	0.13	0.14	0.13	0.17	0.18	0.14	0.13	0.14	0.13	0.17	0.05	0.04	0.04	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.5	1.4	1.5	1.4	1.4	1.4	1.5	1.4	1.5	1.4	1.4	1.4	1.5	1.4	1.5	1.4	1.6	1.6	1.7	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.04	0.04	0.04	0.05	0.05	0.05	0.04	0.04	0.04	0.05	0.05	0.05	0.04	0.05	0.04	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	3	4	3	4
Chloride (Cl)	mg/L	-	-	3.2	2.9	2.8	2.9	2.8	3.2	3.2	2.9	2.8	2.9	2.8	3.2	3.2	2.9	2.8	2.9	2.8	3.2	2.6	2.4	2.4	2.4	2.4	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	6	5	6	6	7	7	6	5	6	6	7	7	6	5	6	6	7	8	7	6	7	7	8
Potassium (K)	mg/L	-	-	0.9	0.7	0.7	0.7	0.7	0.9	0.9	0.7	0.7	0.7	0.7	0.9	0.9	0.7	0.7	0.7	0.7	0.9	0.8	0.6	0.6	0.6	0.6	0.8
Sodium (Na)	mg/L	-	-	1.3	1.7	1.9	1.7	1.8	1.3	1.3	1.7	1.9	1.7	1.8	1.3	1.3	1.7	1.9	1.7	1.8	1.3	2.8	2.8	2.9	2.8	2.9	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0411	0.0379	0.0404	0.0391	0.0497	0.0500	0.0412	0.0380	0.0405	0.0394	0.0497	0.0500	0.0412	0.0382	0.0407	0.0397	0.0497	0.0003	0.0018	0.0021	0.0019	0.0020	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0051	0.0051	0.0051	0.0051	0.0054	0.0055	0.0051	0.0051	0.0051	0.0051	0.0054	0.0055	0.0051	0.0051	0.0051	0.0051	0.0054	0.0002	0.0009	0.0012	0.0010	0.0010	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.060	0.079	0.064	0.071	0.025	0.025	0.059	0.079	0.064	0.070	0.025	0.025	0.059	0.078	0.063	0.069	0.025	0.013	0.050	0.067	0.052	0.057	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.005	0.005	0.005	0.005	0.005	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0041	0.0038	0.0040	0.0039	0.0050	0.0050	0.0041	0.0038	0.0040	0.0039	0.0050	0.0050	0.0041	0.0038	0.0041	0.0040	0.0050	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.016	0.017	0.016	0.017	0.006	0.006	0.016	0.017	0.016	0.017	0.006	0.006	0.016	0.017	0.016	0.016	0.006	0.008	0.017	0.018	0.017	0.017	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	0.9	0.9	0.9	0.9	1.1	1.1	0.9	0.9	0.9	0.9	1.1	1.1	0.9	0.9	0.9	0.9	1.1	1.4	1.1	1.1	1.1	1.1	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.040	0.037	0.040	0.038	0.050	0.050	0.041	0.037	0.040	0.038	0.050	0.050	0.041	0.037	0.040	0.039	0.050	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.06	0.05	0.06	0.06	0.07	0.07	0.06	0.05	0.06	0.06	0.07	0.07	0.06	0.05	0.06	0.06	0.07	0.06	0.05	0.05	0.05	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0033	0.0044	0.0034	0.0038	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.006	0.007	0.006	0.008	0.008	0.007	0.006	0.007	0.006	0.008	0.008	0.007	0.006	0.007	0.007	0.008	0.008	0.007	0.006	0.007	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0048	0.0048	0.0048	0.0048	0.0050	0.0050	0.0048	0.0048	0.0048	0.0048	0.0050	0.0050	0.0048	0.0048	0.0048	0.0048	0.0050	0.0001	0.0009	0.0012	0.0009	0.0010	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	7	7	7	7	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.006	0.006	0.006	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.082	0.076	0.081	0.078	0.099	0.100	0.082	0.076	0.081	0.079	0.099	0.100	0.082	0.076	0.081	0.079	0.099	0.002	0.005	0.005	0.005	0.005	0.002
Vanadium (V)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.013	0.013	0.013	0.013	0.014	0.014	0.013	0.013	0.013	0.013	0.014	0.014	0.013	0.013	0.013	0.013	0.014	0.003	0.004	0.005	0.004	0.004	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-8 Water Quality Results From Mine Area 3,000 m Downstream of Clarification Pond Outlets (continued)

Sahaviara River 3,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	29	29	27	28	32	33	29	29	27	28	32	33	29	29	28	28	32	45	40	40	38	39	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.15	0.15	0.14	0.15	0.17	0.18	0.15	0.15	0.14	0.15	0.17	0.18	0.16	0.15	0.14	0.15	0.17	0.05	0.04	0.04	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.3	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.0	2.9	2.9	2.9	3.2	3.2	3.0	2.9	2.9	2.9	3.2	3.2	3.0	3.0	2.9	2.9	3.2	2.6	2.5	2.5	2.4	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	6	6	6	6	7	7	6	6	6	6	7	7	6	6	6	6	7	8	7	7	7	7	8
Potassium (K)	mg/L	-	-	0.9	0.8	0.8	0.7	0.8	0.9	0.9	0.8	0.8	0.7	0.8	0.9	0.9	0.8	0.8	0.7	0.8	0.9	0.8	0.7	0.7	0.7	0.7	0.7
Sodium (Na)	mg/L	-	-	1.3	1.4	1.4	1.6	1.5	1.3	1.3	1.4	1.4	1.6	1.5	1.3	1.3	1.4	1.4	1.6	1.5	1.3	2.8	2.7	2.7	2.8	2.7	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0446	0.0441	0.0417	0.0428	0.0496	0.0500	0.0447	0.0442	0.0418	0.0429	0.0496	0.0500	0.0448	0.0443	0.0419	0.0430	0.0496	0.0003	0.0009	0.0009	0.0010	0.0009	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0051	0.0051	0.0051	0.0051	0.0054	0.0055	0.0051	0.0051	0.0051	0.0051	0.0054	0.0055	0.0051	0.0051	0.0051	0.0051	0.0054	0.0002	0.0005	0.0005	0.0007	0.0005	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.039	0.040	0.055	0.048	0.025	0.025	0.038	0.040	0.055	0.048	0.025	0.025	0.038	0.039	0.054	0.047	0.025	0.013	0.028	0.027	0.041	0.033	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0045	0.0044	0.0042	0.0043	0.0050	0.0050	0.0045	0.0044	0.0042	0.0043	0.0050	0.0050	0.0045	0.0044	0.0042	0.0043	0.0050	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.009	0.010	0.010	0.010	0.006	0.006	0.009	0.009	0.010	0.010	0.006	0.006	0.009	0.009	0.010	0.010	0.006	0.008	0.011	0.011	0.011	0.011	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.0	1.0	0.9	1.0	1.1	1.1	1.0	1.0	0.9	1.0	1.1	1.1	1.0	1.0	0.9	1.0	1.1	1.4	1.3	1.3	1.2	1.2	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.044	0.044	0.041	0.042	0.050	0.050	0.044	0.044	0.041	0.042	0.050	0.050	0.045	0.044	0.041	0.043	0.050	0.005	0.005	0.005	0.004	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0005	0.0004	0.0004	0.0004	0.0005	0.0005	0.0005	0.0004	0.0004	0.0004	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0016	0.0016	0.0025	0.0020	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0047	0.0047	0.0047	0.0047	0.0050	0.0050	0.0047	0.0047	0.0047	0.0047	0.0050	0.0050	0.0047	0.0047	0.0047	0.0047	0.0050	0.0001	0.0004	0.0004	0.0006	0.0005	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	8	8	8	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.089	0.088	0.083	0.086	0.099	0.100	0.089	0.088	0.084	0.086	0.099	0.100	0.090	0.089	0.084	0.086	0.099	0.002	0.003	0.003	0.003	0.003	0.002
Vanadium (V)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.013	0.013	0.013	0.013	0.014	0.014	0.013	0.013	0.013	0.013	0.014	0.014	0.013	0.013	0.013	0.013	0.014	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-8 Water Quality Results From Mine Area 3,000 m Downstream of Clarification Pond Outlets (continued)

Sahamarirana River 3,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	26	26	28	27	31	33	27	26	28	27	31	33	27	26	28	27	31	45	36	36	38	38	42
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.14	0.13	0.15	0.14	0.17	0.18	0.14	0.14	0.15	0.14	0.17	0.18	0.14	0.14	0.15	0.14	0.17	0.05	0.04	0.04	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.6	1.5	1.5	1.5	1.5	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	3	3	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	2.7	2.7	2.8	2.8	3.1	3.2	2.8	2.7	2.8	2.8	3.1	3.2	2.8	2.7	2.8	2.8	3.1	2.6	2.3	2.3	2.3	2.3	2.5
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	6	6	6	6	7	7	6	6	6	6	7	7	6	6	6	6	7	8	7	7	7	7	8
Potassium (K)	mg/L	-	-	0.9	0.7	0.7	0.8	0.7	0.8	0.9	0.7	0.7	0.8	0.7	0.8	0.9	0.7	0.7	0.8	0.7	0.8	0.8	0.6	0.6	0.7	0.6	0.7
Sodium (Na)	mg/L	-	-	1.3	1.4	1.5	1.3	1.3	1.2	1.3	1.4	1.5	1.3	1.3	1.2	1.3	1.4	1.5	1.3	1.3	1.2	2.8	2.6	2.6	2.5	2.5	2.6
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2	2	1	1	2	2	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0402	0.0395	0.0423	0.0416	0.0476	0.0500	0.0404	0.0397	0.0424	0.0417	0.0476	0.0500	0.0404	0.0399	0.0425	0.0417	0.0476	0.0003	0.0014	0.0014	0.0011	0.0011	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0048	0.0048	0.0048	0.0048	0.0052	0.0055	0.0048	0.0048	0.0048	0.0048	0.0052	0.0055	0.0048	0.0048	0.0048	0.0048	0.0052	0.0002	0.0007	0.0007	0.0004	0.0004	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.045	0.048	0.033	0.036	0.024	0.025	0.044	0.047	0.033	0.036	0.024	0.025	0.044	0.047	0.033	0.036	0.024	0.013	0.035	0.036	0.022	0.024	0.012
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006	0.006	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0040	0.0040	0.0042	0.0042	0.0048	0.0050	0.0040	0.0040	0.0042	0.0042	0.0048	0.0050	0.0040	0.0040	0.0043	0.0042	0.0048	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.015	0.016	0.009	0.008	0.006	0.006	0.015	0.015	0.009	0.008	0.006	0.006	0.015	0.015	0.009	0.008	0.006	0.008	0.016	0.016	0.010	0.009	0.007
Cobalt (Co)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	0.9	0.9	1.0	1.0	1.1	1.1	0.9	0.9	1.0	1.0	1.1	1.1	0.9	0.9	1.0	1.0	1.1	1.4	1.1	1.1	1.2	1.2	1.3
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.040	0.039	0.042	0.041	0.048	0.050	0.040	0.039	0.042	0.041	0.048	0.050	0.040	0.039	0.042	0.041	0.048	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.06	0.05	0.05	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0023	0.0024	0.0013	0.0013	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.007	0.007	0.008	0.008	0.007	0.006	0.007	0.007	0.008	0.008	0.007	0.006	0.007	0.007	0.008	0.008	0.006	0.006	0.007	0.007	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0045	0.0044	0.0044	0.0044	0.0048	0.0050	0.0045	0.0045	0.0044	0.0044	0.0048	0.0050	0.0045	0.0045	0.0045	0.0044	0.0048	0.0001	0.0006	0.0006	0.0003	0.0004	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	7	7	8	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.080	0.079	0.085	0.083	0.095	0.100	0.081	0.079	0.085	0.083	0.095	0.100	0.081	0.080	0.085	0.083	0.095	0.002	0.004	0.004	0.003	0.003	0.002
Vanadium (V)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.012	0.012	0.012	0.012	0.013	0.014	0.012	0.012	0.012	0.012	0.013	0.014	0.012	0.012	0.012	0.012	0.013	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-8 Water Quality Results From Mine Area 3,000 m Downstream of Clarification Pond Outlets (continued)

Torotorofotsy River 3,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	33	31	31	31	33	33	33	31	31	31	33	33	33	31	32	31	33	45	45	41	43	42	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.18	0.16	0.16	0.16	0.17	0.18	0.18	0.16	0.16	0.16	0.17	0.18	0.18	0.16	0.17	0.16	0.17	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.2	3.1	3.1	3.1	3.2	3.2	3.2	3.1	3.1	3.1	3.2	3.2	3.2	3.1	3.1	3.1	3.2	2.6	2.6	2.5	2.6	2.6	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.9	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.8	0.9	0.8	0.9	0.8	0.8	0.7	0.7	0.8	0.8
Sodium (Na)	mg/L	-	-	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	2.8	2.8	2.6	2.7	2.6	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0500	0.0468	0.0472	0.0473	0.0498	0.0500	0.0500	0.0468	0.0476	0.0473	0.0498	0.0500	0.0500	0.0468	0.0481	0.0473	0.0498	0.0003	0.0003	0.0012	0.0010	0.0011	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0002	0.0002	0.0004	0.0003	0.0004	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.025	0.033	0.031	0.031	0.025	0.025	0.025	0.033	0.030	0.031	0.025	0.025	0.025	0.033	0.028	0.031	0.025	0.013	0.013	0.022	0.014	0.020	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0050	0.0047	0.0047	0.0047	0.0050	0.0050	0.0050	0.0047	0.0048	0.0047	0.0050	0.0050	0.0050	0.0047	0.0048	0.0047	0.0050	0.0005	0.0005	0.0006	0.0006	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.006	0.023	0.019	0.021	0.006	0.006	0.006	0.023	0.016	0.021	0.006	0.006	0.006	0.023	0.012	0.021	0.006	0.008	0.008	0.024	0.009	0.023	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.4	1.4	1.3	1.4	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.050	0.047	0.047	0.047	0.050	0.050	0.050	0.047	0.047	0.047	0.050	0.050	0.050	0.047	0.048	0.047	0.050	0.005	0.005	0.005	0.006	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0005	0.0014	0.0006	0.0012	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0001	0.0001	0.0004	0.0002	0.0003	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	9	8	9	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.100	0.094	0.094	0.095	0.100	0.100	0.100	0.094	0.095	0.095	0.100	0.100	0.100	0.094	0.096	0.095	0.100	0.002	0.002	0.004	0.003	0.004	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

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3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-8 Water Quality Results From Mine Area 3,000 m Downstream of Clarification Pond Outlets (continued)

Torotorofotsy River 3,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	33	31	31	31	33	33	33	31	31	31	33	33	33	31	32	31	33	45	45	41	43	42	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.18	0.16	0.16	0.16	0.17	0.18	0.18	0.16	0.16	0.16	0.17	0.18	0.18	0.16	0.17	0.16	0.17	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.2	3.1	3.1	3.1	3.2	3.2	3.2	3.1	3.1	3.1	3.2	3.2	3.2	3.1	3.1	3.1	3.2	2.6	2.6	2.5	2.6	2.6	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.9	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.8	0.9	0.8	0.9	0.8	0.8	0.7	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	2.8	2.8	2.6	2.7	2.6	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0500	0.0468	0.0472	0.0473	0.0498	0.0500	0.0500	0.0468	0.0476	0.0473	0.0498	0.0500	0.0500	0.0468	0.0481	0.0473	0.0498	0.0003	0.0003	0.0012	0.0010	0.0011	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0002	0.0002	0.0004	0.0003	0.0004	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.025	0.033	0.031	0.031	0.025	0.025	0.025	0.033	0.030	0.031	0.025	0.025	0.025	0.033	0.028	0.031	0.025	0.013	0.013	0.022	0.014	0.020	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0050	0.0047	0.0047	0.0047	0.0050	0.0050	0.0050	0.0047	0.0048	0.0047	0.0050	0.0050	0.0050	0.0047	0.0048	0.0047	0.0050	0.0005	0.0005	0.0006	0.0006	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.006	0.023	0.019	0.021	0.006	0.006	0.006	0.023	0.016	0.021	0.006	0.006	0.006	0.023	0.012	0.021	0.006	0.008	0.008	0.024	0.009	0.023	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.4	1.4	1.3	1.4	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.050	0.047	0.047	0.047	0.050	0.050	0.050	0.047	0.047	0.047	0.050	0.050	0.050	0.047	0.048	0.047	0.050	0.005	0.005	0.005	0.006	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0005	0.0014	0.0006	0.0012	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0001	0.0001	0.0004	0.0002	0.0003	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	9	8	9	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.100	0.094	0.094	0.095	0.100	0.100	0.100	0.094	0.095	0.095	0.100	0.100	0.100	0.094	0.096	0.095	0.100	0.002	0.002	0.004	0.003	0.004	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-8 Water Quality Results From Mine Area 3,000 m Downstream of Clarification Pond Outlets (continued)

Antsahalava River 3,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	36	34	36	36	44	45	36	34	36	36	44	45	36	34	36	36	44	45	36	34	36	36	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	3	4	3	4	4	4	3	4	3	4	4	4	3	4	3	4	4	4	3	4	3	4
Chloride (Cl)	mg/L	-	-	2.6	2.4	2.4	2.4	2.4	2.6	2.6	2.4	2.4	2.4	2.4	2.6	2.6	2.4	2.4	2.4	2.4	2.6	2.6	2.4	2.4	2.4	2.4	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	6	7	7	8	8	7	6	7	7	8	8	7	6	7	7	8	8	7	6	7	7	8
Potassium (K)	mg/L	-	-	0.8	0.6	0.6	0.6	0.6	0.8	0.8	0.6	0.6	0.6	0.6	0.8	0.8	0.6	0.6	0.6	0.6	0.8	0.8	0.6	0.6	0.6	0.6	0.8
Sodium (Na)	mg/L	-	-	2.8	2.8	2.9	2.8	2.9	2.7	2.8	2.8	2.9	2.8	2.9	2.7	2.8	2.8	2.9	2.8	2.9	2.7	2.8	2.8	2.9	2.8	2.9	2.7
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0018	0.0021	0.0019	0.0020	0.0003	0.0003	0.0018	0.0021	0.0019	0.0020	0.0003	0.0003	0.0018	0.0021	0.0019	0.0020	0.0003	0.0003	0.0018	0.0021	0.0019	0.0020	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0009	0.0012	0.0010	0.0010	0.0002	0.0002	0.0009	0.0012	0.0010	0.0010	0.0002	0.0002	0.0009	0.0012	0.0010	0.0010	0.0002	0.0002	0.0009	0.0012	0.0010	0.0010	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.050	0.067	0.052	0.057	0.013	0.013	0.050	0.067	0.052	0.057	0.013	0.013	0.050	0.067	0.052	0.057	0.013	0.013	0.050	0.067	0.052	0.057	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.017	0.018	0.017	0.017	0.008	0.008	0.017	0.018	0.017	0.017	0.008	0.008	0.017	0.018	0.017	0.017	0.008	0.008	0.017	0.018	0.017	0.017	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.1	1.1	1.1	1.1	1.4	1.4	1.1	1.1	1.1	1.1	1.4	1.4	1.1	1.1	1.1	1.1	1.4	1.4	1.1	1.1	1.1	1.1	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0033	0.0044	0.0034	0.0038	0.0005	0.0005	0.0033	0.0044	0.0034	0.0038	0.0005	0.0005	0.0033	0.0044	0.0034	0.0038	0.0005	0.0005	0.0033	0.0044	0.0034	0.0038	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.006	0.007	0.006	0.008	0.008	0.007	0.006	0.007	0.006	0.008	0.008	0.007	0.006	0.007	0.006	0.008	0.008	0.007	0.006	0.007	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0009	0.0012	0.0009	0.0010	0.0001	0.0001	0.0009	0.0012	0.0009	0.0010	0.0001	0.0001	0.0009	0.0012	0.0009	0.0010	0.0001	0.0001	0.0009	0.0012	0.0009	0.0010	0.0001
Silicon (Si)	mg/L	-	-	9	7	7	7	7	9	9	7	7	7	7	9	9	7	7	7	7	9	9	7	7	7	7	9
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.006	0.006	0.006	0.004	0.005	0.006	0.006	0.006	0.006	0.004	0.005	0.006	0.006	0.006	0.006	0.004	0.005	0.006	0.006	0.006	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.005	0.005	0.005	0.005	0.002	0.002	0.005	0.005	0.005	0.005	0.002	0.002	0.005	0.005	0.005	0.005	0.002	0.002	0.005	0.005	0.005	0.005	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.004	0.005	0.004	0.004	0.002	0.003	0.004	0.005	0.004	0.004	0.002	0.003	0.004	0.005	0.004	0.004	0.002	0.003	0.004	0.005	0.004	0.004	0.002

Notes

1

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2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-8 Water Quality Results From Mine Area 3,000 m Downstream of Clarification Pond Outlets (continued)

Sahaviara River 3,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	40	40	38	39	44	45	40	40	38	39	44	45	40	40	38	39	44	45	40	40	38	39	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.5	2.5	2.4	2.5	2.6	2.6	2.5	2.5	2.4	2.5	2.6	2.6	2.5	2.5	2.4	2.5	2.6	2.6	2.5	2.5	2.4	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	7	7	7	8	8	7	7	7	7	8	8	7	7	7	7	8	8	7	7	7	7	8
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7
Sodium (Na)	mg/L	-	-	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0009	0.0009	0.0010	0.0009	0.0003	0.0003	0.0009	0.0009	0.0010	0.0009	0.0003	0.0003	0.0009	0.0009	0.0010	0.0009	0.0003	0.0003	0.0009	0.0009	0.0010	0.0009	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0005	0.0005	0.0007	0.0005	0.0002	0.0002	0.0005	0.0005	0.0007	0.0005	0.0002	0.0002	0.0005	0.0005	0.0007	0.0005	0.0002	0.0002	0.0005	0.0005	0.0007	0.0005	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.028	0.027	0.041	0.033	0.013	0.013	0.028	0.027	0.041	0.033	0.013	0.013	0.028	0.027	0.041	0.033	0.013	0.013	0.028	0.027	0.041	0.033	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.011	0.011	0.011	0.011	0.008	0.008	0.011	0.011	0.011	0.011	0.008	0.008	0.011	0.011	0.011	0.011	0.008	0.008	0.011	0.011	0.011	0.011	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.3	1.3	1.2	1.2	1.4	1.4	1.3	1.3	1.2	1.2	1.4	1.4	1.3	1.3	1.2	1.2	1.4	1.4	1.3	1.3	1.2	1.2	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0016	0.0016	0.0025	0.0020	0.0005	0.0005	0.0016	0.0016	0.0025	0.0020	0.0005	0.0005	0.0016	0.0016	0.0025	0.0020	0.0005	0.0005	0.0016	0.0016	0.0025	0.0020	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0004	0.0004	0.0006	0.0005	0.0001	0.0001	0.0004	0.0004	0.0006	0.0005	0.0001	0.0001	0.0004	0.0004	0.0006	0.0005	0.0001	0.0001	0.0004	0.0004	0.0006	0.0005	0.0001
Silicon (Si)	mg/L	-	-	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-8 Water Quality Results From Mine Area 3,000 m Downstream of Clarification Pond Outlets (continued)

Sahamarirana River 3,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	36	36	38	38	42	45	36	36	38	38	42	45	36	36	38	38	42	45	36	36	38	38	42
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	3	3	4	4	4	4	3	3	4	4	4	4	3	3	4	4	4	4	3	3	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.3	2.3	2.3	2.3	2.5	2.6	2.3	2.3	2.3	2.3	2.5	2.6	2.3	2.3	2.3	2.3	2.5	2.6	2.3	2.3	2.3	2.3	2.5
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	7	7	7	8	8	7	7	7	7	8	8	7	7	7	7	8	8	7	7	7	7	8
Potassium (K)	mg/L	-	-	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7
Sodium (Na)	mg/L	-	-	2.8	2.6	2.6	2.5	2.5	2.6	2.8	2.6	2.6	2.5	2.5	2.6	2.8	2.6	2.6	2.5	2.5	2.6	2.8	2.6	2.6	2.5	2.5	2.6
Sulphate (SO ₄)	mg/L	-	-	1	2	2	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0014	0.0014	0.0011	0.0011	0.0003	0.0003	0.0014	0.0014	0.0011	0.0011	0.0003	0.0003	0.0014	0.0014	0.0011	0.0011	0.0003	0.0003	0.0014	0.0014	0.0011	0.0011	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0007	0.0007	0.0004	0.0004	0.0002	0.0002	0.0007	0.0007	0.0004	0.0004	0.0002	0.0002	0.0007	0.0007	0.0004	0.0004	0.0002	0.0002	0.0007	0.0007	0.0004	0.0004	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.035	0.036	0.022	0.024	0.012	0.013	0.035	0.036	0.022	0.024	0.012	0.013	0.035	0.036	0.022	0.024	0.012	0.013	0.035	0.036	0.022	0.024	0.012
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.016	0.016	0.010	0.009	0.007	0.008	0.016	0.016	0.010	0.009	0.007	0.008	0.016	0.016	0.010	0.009	0.007	0.008	0.016	0.016	0.010	0.009	0.007
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.1	1.1	1.2	1.2	1.3	1.4	1.1	1.1	1.2	1.2	1.3	1.4	1.1	1.1	1.2	1.2	1.3	1.4	1.1	1.1	1.2	1.2	1.3
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.06	0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0023	0.0024	0.0013	0.0013	0.0005	0.0005	0.0023	0.0024	0.0013	0.0013	0.0005	0.0005	0.0023	0.0024	0.0013	0.0013	0.0005	0.0005	0.0023	0.0024	0.0013	0.0013	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.007	0.007	0.007	0.008	0.006	0.006	0.007	0.007	0.007	0.008	0.006	0.006	0.007	0.007	0.007	0.008	0.006	0.006	0.007	0.007	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0006	0.0006	0.0003	0.0004	0.0001	0.0001	0.0006	0.0006	0.0003	0.0004	0.0001	0.0001	0.0006	0.0006	0.0003	0.0004	0.0001	0.0001	0.0006	0.0006	0.0003	0.0004	0.0001
Silicon (Si)	mg/L	-	-	9	7	7	8	8	9	9	7	7	8	8	9	9	7	7	8	8	9	9	7	7	8	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.004	0.004	0.003	0.003	0.002	0.002	0.004	0.004	0.003	0.003	0.002	0.002	0.004	0.004	0.003	0.003	0.002	0.002	0.004	0.004	0.003	0.003	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002

- Notes
- 1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.
- 2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.
- 3

Based on the un-ionized portion of ammonia.
- 4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.
- 5

Based on long-term exposure.
- 6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.
- 7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.
- 8

Based on an alkalinity value of less than 60 mg/L.
- 9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).
- 10

Based on the dissolved form of this metal.
- 11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.
- 12

Based on a dissolved saturation of at least 80%.
- 13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.
- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-8 Water Quality Results From Mine Area 3,000 m Downstream of Clarification Pond Outlets (continued)

Torotorofotsy River 3,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	41	43	42	44	45	45	41	43	42	44	45	45	41	43	42	44	45	45	41	43	42	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.5	2.6	2.6	2.6	2.6	2.6	2.5	2.6	2.6	2.6	2.6	2.6	2.5	2.6	2.6	2.6	2.6	2.6	2.5	2.6	2.6	
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.8	
Sodium (Na)	mg/L	-	-	2.8	2.8	2.6	2.7	2.6	2.7	2.8	2.8	2.6	2.7	2.6	2.7	2.8	2.8	2.6	2.7	2.6	2.7	2.8	2.8	2.6	2.7	2.6	
Sulphate (SO ₄)	mg/L	-	-	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0012	0.0010	0.0011	0.0003	0.0003	0.0003	0.0012	0.0010	0.0011	0.0003	0.0003	0.0003	0.0012	0.0010	0.0011	0.0003	0.0003	0.0003	0.0012	0.0010		
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0004	0.0003	0.0004	0.0002	0.0002	0.0002	0.0004	0.0003	0.0004	0.0002	0.0002	0.0002	0.0004	0.0003	0.0004	0.0002	0.0002	0.0002	0.0004	0.0003		
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.022	0.014	0.020	0.013	0.013	0.013	0.022	0.014	0.020	0.013	0.013	0.013	0.022	0.014	0.020	0.013	0.013	0.013	0.022	0.014		
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004		
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0006	0.0006	0.0005	0.0005	0.0005	0.0005	0.0006	0.0006	0.0005	0.0005	0.0005	0.0005	0.0006	0.0006	0.0005	0.0005	0.0005	0.0005	0.0006	0.0006		
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.024	0.009	0.023	0.008	0.008	0.008	0.024	0.009	0.023	0.008	0.008	0.008	0.024	0.009	0.023	0.008	0.008	0.008	0.024	0.009		
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002		
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005		
Iron (Fe)	mg/L	-	-	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4		
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.006	0.005		
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06		
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002		
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0014	0.0006	0.0012	0.0005	0.0005	0.0005	0.0014	0.0006	0.0012	0.0005	0.0005	0.0005	0.0014	0.0006	0.0012	0.0005	0.0005	0.0005	0.0014	0.0006		
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.008	0.007	0.008	0.008	0.008	0.007	0.008	0.007	0.008	0.008	0.008	0.007	0.008	0.007	0.008	0.008	0.008	0.007	0.008		
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0004	0.0002	0.0003	0.0001	0.0001	0.0001	0.0004	0.0002	0.0003	0.0001	0.0001	0.0001	0.0004	0.0002	0.0003	0.0001	0.0001	0.0001	0.0004	0.0002		
Silicon (Si)	mg/L	-	-	9	9	8	9	8	9	9	9	8	9	8	9	9	9	8	9	8	9	9	9	8	9	8	
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005		
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.004	0.003	0.004	0.002	0.002	0.002	0.004	0.003	0.004	0.002	0.002	0.002	0.004	0.003	0.004	0.002	0.002	0.002	0.004	0.003		
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001		
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003		

- Notes
- 1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.
- 2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.
- 3

Based on the un-ionized portion of ammonia.
- 4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.
- 5

Based on long-term exposure.
- 6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.
- 7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.
- 8

Based on an alkalinity value of less than 60 mg/L.
- 9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).
- 10

Based on the dissolved form of this metal.
- 11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.
- 12

Based on a dissolved saturation of at least 80%.
- 13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.
- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-8 Water Quality Results From Mine Area 3,000 m Downstream of Clarification Pond Outlets (continued)

Ankaja River 3,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	39	39	41	39	43	45	39	39	41	39	43	45	39	39	41	39	43	45	39	39	41	39	43
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.4	2.4	2.5	2.4	2.5	2.6	2.4	2.4	2.5	2.4	2.5	2.6	2.4	2.4	2.5	2.4	2.5	2.6	2.4	2.4	2.5	2.4	2.5
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	7	8	7	8	8	7	7	8	7	8	8	7	7	8	7	8	8	7	7	8	7	8
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7
Sodium (Na)	mg/L	-	-	2.8	2.5	2.5	2.5	2.5	2.6	2.8	2.5	2.5	2.5	2.5	2.6	2.8	2.5	2.5	2.5	2.5	2.6	2.8	2.5	2.5	2.5	2.5	2.6
Sulphate (SO ₄)	mg/L	-	-	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0015	0.0015	0.0014	0.0017	0.0003	0.0003	0.0015	0.0015	0.0014	0.0017	0.0003	0.0003	0.0015	0.0015	0.0014	0.0017	0.0003	0.0003	0.0015	0.0015	0.0014	0.0017	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0005	0.0005	0.0003	0.0005	0.0002	0.0002	0.0005	0.0005	0.0003	0.0005	0.0002	0.0002	0.0005	0.0005	0.0003	0.0005	0.0002	0.0002	0.0005	0.0005	0.0003	0.0005	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.024	0.023	0.012	0.024	0.013	0.013	0.024	0.023	0.012	0.024	0.013	0.013	0.024	0.023	0.012	0.024	0.013	0.013	0.024	0.023	0.012	0.024	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.031	0.026	0.007	0.032	0.008	0.008	0.031	0.026	0.007	0.032	0.008	0.008	0.031	0.026	0.007	0.032	0.008	0.008	0.031	0.026	0.007	0.032	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.2	1.2	1.3	1.2	1.4	1.4	1.2	1.2	1.3	1.2	1.4	1.4	1.2	1.2	1.3	1.2	1.4	1.4	1.2	1.2	1.3	1.2	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0016	0.0015	0.0005	0.0016	0.0005	0.0005	0.0016	0.0015	0.0005	0.0016	0.0005	0.0005	0.0016	0.0015	0.0005	0.0016	0.0005	0.0005	0.0016	0.0015	0.0005	0.0016	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0005	0.0004	0.0002	0.0005	0.0001	0.0001	0.0005	0.0004	0.0002	0.0005	0.0001	0.0001	0.0005	0.0004	0.0002	0.0005	0.0001	0.0001	0.0005	0.0004	0.0002	0.0005	0.0001
Silicon (Si)	mg/L	-	-	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.004	0.004	0.004	0.005	0.002	0.002	0.004	0.004	0.004	0.005	0.002	0.002	0.004	0.004	0.004	0.005	0.002	0.002	0.004	0.004	0.004	0.005	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-8 Water Quality Results From Mine Area 3,000 m Downstream of Clarification Pond Outlets (continued)

Antsahalava River 3,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	36	34	36	36	44	45	36	34	36	36	44	45	36	34	36	36	44	33	27	25	27	26	33
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.18	0.14	0.13	0.14	0.13	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.4	1.4	1.5	1.4	1.5	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.04	0.04	0.04	0.05
Calcium (Ca)	mg/L	-	-	4	4	3	4	3	4	4	4	3	4	3	4	4	4	3	4	3	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.4	2.4	2.4	2.4	2.6	2.6	2.4	2.4	2.4	2.4	2.6	2.6	2.4	2.4	2.4	2.4	2.6	3.2	2.9	2.8	2.9	2.8	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	6	7	7	8	8	7	6	7	7	8	8	7	6	7	7	8	7	6	5	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.6	0.6	0.6	0.6	0.8	0.8	0.6	0.6	0.6	0.6	0.8	0.8	0.6	0.6	0.6	0.6	0.8	0.9	0.7	0.7	0.7	0.7	0.9
Sodium (Na)	mg/L	-	-	2.8	2.8	2.9	2.8	2.9	2.7	2.8	2.8	2.9	2.8	2.9	2.7	2.8	2.8	2.9	2.8	2.9	2.7	1.3	1.7	1.9	1.7	1.8	1.3
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0018	0.0021	0.0019	0.0020	0.0003	0.0003	0.0018	0.0021	0.0019	0.0020	0.0003	0.0003	0.0018	0.0021	0.0019	0.0020	0.0003	0.0500	0.0412	0.0380	0.0405	0.0394	0.0497
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0009	0.0012	0.0010	0.0010	0.0002	0.0002	0.0009	0.0012	0.0010	0.0010	0.0002	0.0002	0.0009	0.0012	0.0010	0.0010	0.0002	0.0055	0.0051	0.0051	0.0051	0.0051	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.050	0.067	0.052	0.057	0.013	0.013	0.050	0.067	0.052	0.057	0.013	0.013	0.050	0.067	0.052	0.057	0.013	0.025	0.059	0.079	0.064	0.070	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.007	0.006	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0050	0.0041	0.0038	0.0040	0.0039	0.0050
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.017	0.018	0.017	0.017	0.008	0.008	0.017	0.018	0.017	0.017	0.008	0.008	0.017	0.018	0.017	0.017	0.008	0.006	0.016	0.017	0.016	0.017	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.005	0.004	0.004	0.004	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.1	1.1	1.1	1.1	1.4	1.4	1.1	1.1	1.1	1.1	1.4	1.4	1.1	1.1	1.1	1.1	1.4	1.1	0.9	0.9	0.9	0.9	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.041	0.037	0.040	0.038	0.050
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.07	0.06	0.05	0.06	0.06	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0033	0.0044	0.0034	0.0038	0.0005	0.0005	0.0033	0.0044	0.0034	0.0038	0.0005	0.0005	0.0033	0.0044	0.0034	0.0038	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.006	0.007	0.006	0.008	0.008	0.007	0.006	0.007	0.006	0.008	0.008	0.007	0.006	0.007	0.006	0.008	0.008	0.007	0.006	0.007	0.006	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0009	0.0012	0.0009	0.0010	0.0001	0.0001	0.0009	0.0012	0.0009	0.0010	0.0001	0.0001	0.0009	0.0012	0.0009	0.0010	0.0001	0.0050	0.0048	0.0048	0.0048	0.0048	0.0050
Silicon (Si)	mg/L	-	-	9	7	7	7	7	9	9	7	7	7	7	9	9	7	7	7	7	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.006	0.006	0.006	0.006	0.004	0.005	0.006	0.006	0.006	0.006	0.004	0.005	0.006	0.006	0.006	0.006	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.005	0.005	0.005	0.005	0.002	0.002	0.005	0.005	0.005	0.005	0.002	0.002	0.005	0.005	0.005	0.005	0.002	0.100	0.082	0.076	0.081	0.079	0.099
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.004	0.004	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.004	0.005	0.004	0.004	0.002	0.003	0.004	0.005	0.004	0.004	0.002	0.003	0.004	0.005	0.004	0.004	0.002	0.014	0.013	0.013	0.013	0.013	0.014

- Notes
- 1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.
- 2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.
- 3

Based on the un-ionized portion of ammonia.
- 4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.
- 5

Based on long-term exposure.
- 6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.
- 7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.
- 8

Based on an alkalinity value of less than 60 mg/L.
- 9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).
- 10

Based on the dissolved form of this metal.
- 11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.
- 12

Based on a dissolved saturation of at least 80%.
- 13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.
- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-8 Water Quality Results From Mine Area 3,000 m Downstream of Clarification Pond Outlets (continued)

Sahaviara River 3,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	40	40	38	39	44	45	40	40	38	39	44	45	40	40	38	39	44	33	29	29	27	28	32
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.18	0.15	0.15	0.14	0.15	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.4	1.4	1.4	1.4	1.4	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.5	2.5	2.4	2.5	2.6	2.6	2.5	2.5	2.4	2.5	2.6	2.6	2.5	2.5	2.4	2.4	2.6	3.2	3.0	2.9	2.9	2.9	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	7	7	7	8	8	7	7	7	7	8	8	7	7	7	7	8	7	6	6	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.9	0.8	0.8	0.7	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	1.3	1.4	1.4	1.6	1.5	1.3
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0009	0.0009	0.0010	0.0009	0.0003	0.0003	0.0009	0.0009	0.0010	0.0009	0.0003	0.0003	0.0009	0.0009	0.0010	0.0009	0.0003	0.0500	0.0448	0.0442	0.0418	0.0429	0.0496
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0005	0.0005	0.0007	0.0005	0.0002	0.0002	0.0005	0.0005	0.0007	0.0005	0.0002	0.0002	0.0005	0.0005	0.0007	0.0006	0.0002	0.0055	0.0051	0.0051	0.0051	0.0051	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.028	0.027	0.041	0.033	0.013	0.013	0.028	0.027	0.041	0.033	0.013	0.013	0.028	0.027	0.041	0.034	0.013	0.025	0.038	0.040	0.055	0.048	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.006	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0045	0.0044	0.0042	0.0043	0.0050
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.011	0.011	0.011	0.011	0.008	0.008	0.011	0.011	0.011	0.011	0.008	0.008	0.011	0.011	0.011	0.011	0.008	0.006	0.009	0.009	0.010	0.010	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.005	0.004	0.004	0.004	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.3	1.3	1.2	1.2	1.4	1.4	1.3	1.3	1.2	1.2	1.4	1.4	1.3	1.3	1.2	1.2	1.4	1.1	1.0	1.0	0.9	1.0	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.050	0.044	0.044	0.041	0.042	0.050
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0004	0.0004	0.0004	0.0005	
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0016	0.0016	0.0025	0.0020	0.0005	0.0005	0.0016	0.0016	0.0025	0.0020	0.0005	0.0005	0.0016	0.0016	0.0025	0.0020	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0004	0.0004	0.0006	0.0005	0.0001	0.0001	0.0004	0.0004	0.0006	0.0005	0.0001	0.0001	0.0004	0.0004	0.0006	0.0005	0.0001	0.0050	0.0047	0.0047	0.0047	0.0047	0.0050
Silicon (Si)	mg/L	-	-	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.100	0.090	0.088	0.084	0.086	0.099
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.004	0.004	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.014	0.013	0.013	0.013	0.013	0.014

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-8 Water Quality Results From Mine Area 3,000 m Downstream of Clarification Pond Outlets (continued)

Sahamarirana River 3,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	36	36	38	38	42	45	36	36	38	38	42	45	36	36	38	38	42	33	27	26	28	27	31
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.18	0.14	0.14	0.15	0.14	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.4	1.3	1.3	1.3	1.3	1.3
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.04	0.04	0.04	0.04	0.05
Calcium (Ca)	mg/L	-	-	4	3	3	4	4	4	4	3	3	4	4	4	4	3	3	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.3	2.3	2.3	2.3	2.5	2.6	2.3	2.3	2.3	2.3	2.5	2.6	2.3	2.3	2.3	2.3	2.5	3.2	2.8	2.7	2.8	2.8	3.1
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	8	7	7	7	7	8	8	7	7	7	7	8	8	7	7	7	7	8	7	6	6	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7	0.8	0.6	0.6	0.7	0.6	0.7	0.9	0.7	0.7	0.8	0.7	0.8
Sodium (Na)	mg/L	-	-	2.8	2.6	2.6	2.5	2.5	2.6	2.8	2.6	2.6	2.5	2.5	2.6	2.8	2.6	2.6	2.5	2.5	2.6	1.3	1.4	1.5	1.3	1.3	1.2
Sulphate (SO ₄)	mg/L	-	-	1	2	2	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1	2	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0014	0.0014	0.0011	0.0011	0.0003	0.0003	0.0014	0.0014	0.0011	0.0011	0.0003	0.0003	0.0014	0.0014	0.0011	0.0011	0.0003	0.0500	0.0404	0.0397	0.0424	0.0417	0.0476
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0007	0.0007	0.0004	0.0004	0.0002	0.0002	0.0007	0.0007	0.0004	0.0004	0.0002	0.0002	0.0007	0.0007	0.0004	0.0004	0.0002	0.0055	0.0048	0.0048	0.0048	0.0048	0.0052
Barium (Ba)	mg/L	0.7	-	0.013	0.035	0.036	0.022	0.024	0.012	0.013	0.035	0.036	0.022	0.024	0.012	0.013	0.035	0.036	0.022	0.024	0.012	0.025	0.044	0.047	0.033	0.036	0.024
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.006	0.006	0.006	0.006	0.006
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0040	0.0040	0.0042	0.0042	0.0048
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.016	0.016	0.010	0.009	0.007	0.008	0.016	0.016	0.010	0.009	0.007	0.008	0.016	0.016	0.010	0.009	0.007	0.006	0.015	0.015	0.009	0.008	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.005	0.004	0.004	0.004	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.1	1.1	1.2	1.2	1.3	1.4	1.1	1.1	1.2	1.2	1.3	1.4	1.1	1.1	1.2	1.2	1.3	1.1	0.9	0.9	1.0	1.0	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.040	0.039	0.042	0.041	0.048
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.05	0.05	0.06	0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0023	0.0024	0.0013	0.0013	0.0005	0.0005	0.0023	0.0024	0.0013	0.0013	0.0005	0.0005	0.0023	0.0024	0.0013	0.0013	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.006	0.006	0.007	0.007	0.007	0.008	0.006	0.006	0.007	0.007	0.007	0.008	0.006	0.006	0.007	0.007	0.007	0.008	0.007	0.006	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0006	0.0006	0.0003	0.0004	0.0001	0.0001	0.0006	0.0006	0.0003	0.0004	0.0001	0.0001	0.0006	0.0006	0.0003	0.0004	0.0001	0.0050	0.0045	0.0045	0.0044	0.0044	0.0048
Silicon (Si)	mg/L	-	-	9	7	7	8	8	9	9	7	7	8	8	9	9	7	7	8	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.004	0.004	0.003	0.003	0.002	0.002	0.004	0.004	0.003	0.003	0.002	0.002	0.004	0.004	0.003	0.003	0.002	0.100	0.081	0.079	0.085	0.083	0.095
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.004	0.004	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.014	0.012	0.012	0.012	0.012	0.013

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-8 Water Quality Results From Mine Area 3,000 m Downstream of Clarification Pond Outlets (continued)

Torotorofotsy River 3,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	41	43	42	44	45	45	41	43	42	44	45	45	41	43	42	44	33	33	31	31	31	33
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.18	0.18	0.16	0.16	0.16	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.4	1.4	1.4	1.4	1.4	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.5	2.6	2.6	2.6	2.6	2.6	2.5	2.6	2.6	2.6	2.6	2.6	2.5	2.6	2.6	2.6	3.2	3.2	3.1	3.1	3.1	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7	7	7	7	7	7
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.9	0.9	0.8	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.8	2.6	2.7	2.6	2.7	2.8	2.8	2.6	2.7	2.6	2.7	2.8	2.8	2.6	2.7	2.6	2.7	1.3	1.3	1.3	1.3	1.3	1.3
Sulphate (SO ₄)	mg/L	-	-	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0012	0.0010	0.0011	0.0003	0.0003	0.0003	0.0012	0.0010	0.0011	0.0003	0.0003	0.0003	0.0012	0.0010	0.0011	0.0003	0.0500	0.0500	0.0468	0.0476	0.0473	0.0498
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0004	0.0003	0.0004	0.0002	0.0002	0.0002	0.0004	0.0003	0.0004	0.0002	0.0002	0.0002	0.0004	0.0003	0.0004	0.0002	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.022	0.014	0.020	0.013	0.013	0.013	0.022	0.014	0.020	0.013	0.013	0.013	0.022	0.014	0.020	0.013	0.025	0.025	0.033	0.030	0.031	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.007	0.007	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0006	0.0006	0.0005	0.0005	0.0005	0.0005	0.0006	0.0006	0.0005	0.0005	0.0005	0.0005	0.0006	0.0006	0.0005	0.0005	0.0050	0.0050	0.0047	0.0048	0.0047	0.0050
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.024	0.009	0.023	0.008	0.008	0.008	0.024	0.009	0.023	0.008	0.008	0.008	0.024	0.009	0.023	0.008	0.006	0.006	0.023	0.016	0.021	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.4	1.1	1.1	1.1	1.1	1.1	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.050	0.050	0.047	0.047	0.047	0.050
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0014	0.0006	0.0012	0.0005	0.0005	0.0005	0.0014	0.0006	0.0012	0.0005	0.0005	0.0005	0.0014	0.0006	0.0012	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.008	0.007	0.008	0.008	0.008	0.007	0.008	0.007	0.008	0.008	0.008	0.007	0.008	0.007	0.008	0.008	0.008	0.008	0.008	0.008	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0004	0.0002	0.0003	0.0001	0.0001	0.0001	0.0004	0.0002	0.0003	0.0001	0.0001	0.0001	0.0004	0.0002	0.0003	0.0001	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050
Silicon (Si)	mg/L	-	-	9	9	8	9	8	9	9	9	8	9	8	9	9	9	8	9	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.004	0.003	0.004	0.002	0.002	0.002	0.004	0.003	0.004	0.002	0.002	0.002	0.004	0.003	0.004	0.002	0.100	0.100	0.094	0.095	0.095	0.100
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.014	0.014	0.013	0.013	0.013	0.014

- Notes
- ¹ World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.
 - ² Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.
 - ³ Based on the un-ionized portion of ammonia.
 - ⁴ Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.
 - ⁵ Based on long-term exposure.
 - ⁶ Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.
 - ⁷ Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.
 - ⁸ Based on an alkalinity value of less than 60 mg/L.
 - ⁹ Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).
 - ¹⁰ Based on the dissolved form of this metal.
 - ¹¹ Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.
 - ¹² Based on a dissolved saturation of at least 80%.
 - ¹³ Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.
 - No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-8 Water Quality Results From Mine Area 3,000 m Downstream of Clarification Pond Outlets (continued)

Ankaja River 3,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	39	39	41	39	43	45	39	39	41	39	43	45	39	39	41	39	43	33	29	29	29	29	32
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05	0.18	0.15	0.15	0.15	0.15	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.4	1.3	1.3	1.3	1.3	1.3
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.4	2.4	2.5	2.4	2.5	2.6	2.4	2.4	2.5	2.4	2.5	2.6	2.4	2.4	2.5	2.4	2.5	3.2	2.9	2.9	2.9	2.9	3.1
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	8	7	7	8	7	8	8	7	7	8	7	8	8	7	7	8	7	8	7	6	6	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.9	0.8	0.8	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.5	2.5	2.5	2.5	2.6	2.8	2.5	2.5	2.5	2.5	2.6	2.8	2.5	2.5	2.5	2.5	2.6	1.3	1.2	1.2	1.2	1.2	1.2
Sulphate (SO ₄)	mg/L	-	-	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	2	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0015	0.0015	0.0014	0.0017	0.0003	0.0003	0.0015	0.0015	0.0014	0.0017	0.0003	0.0003	0.0015	0.0015	0.0014	0.0017	0.0003	0.0500	0.0440	0.0441	0.0445	0.0439	0.0482
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0005	0.0005	0.0003	0.0005	0.0002	0.0002	0.0005	0.0005	0.0003	0.0005	0.0002	0.0002	0.0005	0.0005	0.0003	0.0005	0.0002	0.0055	0.0051	0.0050	0.0051	0.0050	0.0053
Barium (Ba)	mg/L	0.7	-	0.013	0.024	0.023	0.012	0.024	0.013	0.013	0.024	0.023	0.012	0.024	0.013	0.013	0.024	0.023	0.013	0.024	0.013	0.025	0.034	0.033	0.032	0.034	0.024
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.006	0.006	0.006	0.006	0.006
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0005	0.0050	0.0044	0.0044	0.0044	0.0044	0.0048
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.031	0.026	0.007	0.032	0.008	0.008	0.031	0.026	0.007	0.032	0.008	0.008	0.031	0.026	0.008	0.032	0.008	0.006	0.029	0.024	0.026	0.030	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.004	0.004	0.004	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.2	1.2	1.3	1.2	1.4	1.4	1.2	1.2	1.3	1.2	1.4	1.4	1.2	1.2	1.3	1.2	1.4	1.1	1.0	1.0	1.0	1.0	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.050	0.044	0.044	0.044	0.044	0.048
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0016	0.0015	0.0005	0.0016	0.0005	0.0005	0.0016	0.0015	0.0005	0.0016	0.0005	0.0005	0.0016	0.0015	0.0005	0.0016	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0005	0.0004	0.0002	0.0005	0.0001	0.0001	0.0005	0.0004	0.0002	0.0005	0.0001	0.0001	0.0005	0.0004	0.0002	0.0005	0.0001	0.0050	0.0047	0.0046	0.0047	0.0047	0.0048
Silicon (Si)	mg/L	-	-	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.004	0.004	0.004	0.005	0.002	0.002	0.004	0.004	0.004	0.005	0.002	0.002	0.004	0.004	0.004	0.005	0.002	0.100	0.088	0.088	0.089	0.088	0.096
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.004	0.004	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.014	0.012	0.012	0.012	0.012	0.013

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-9 Water Quality Results From Mine Area 5,000 m Downstream of Clarification Pond Outlets

Antsahalava River 5,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	29	27	28	28	33	33	29	27	28	28	33	33	29	27	29	28	33	45	39	37	39	38	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.15	0.14	0.15	0.14	0.17	0.18	0.15	0.14	0.15	0.14	0.17	0.18	0.15	0.14	0.15	0.15	0.17	0.05	0.04	0.04	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.5	1.4	1.4	1.4	1.4	1.4	1.5	1.4	1.4	1.4	1.4	1.4	1.5	1.4	1.4	1.4	1.6	1.6	1.7	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.0	2.9	3.0	2.9	3.2	3.2	3.0	2.9	3.0	2.9	3.2	3.2	3.0	2.9	3.0	3.0	3.2	2.6	2.5	2.5	2.5	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	6	6	6	6	7	7	6	6	6	6	7	7	6	6	6	6	7	8	7	7	7	7	8
Potassium (K)	mg/L	-	-	0.9	0.8	0.7	0.8	0.8	0.9	0.9	0.8	0.7	0.8	0.8	0.9	0.9	0.8	0.7	0.8	0.8	0.9	0.8	0.7	0.6	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	1.3	1.5	1.7	1.6	1.7	1.3	1.3	1.5	1.7	1.6	1.6	1.3	1.3	1.5	1.7	1.6	1.6	1.3	2.8	2.8	2.9	2.8	2.8	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0438	0.0414	0.0431	0.0422	0.0498	0.0500	0.0439	0.0415	0.0432	0.0424	0.0498	0.0500	0.0439	0.0416	0.0434	0.0427	0.0498	0.0003	0.0013	0.0015	0.0014	0.0015	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0052	0.0052	0.0052	0.0052	0.0054	0.0055	0.0052	0.0052	0.0052	0.0052	0.0054	0.0055	0.0052	0.0052	0.0052	0.0052	0.0054	0.0002	0.0007	0.0009	0.0007	0.0008	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.049	0.064	0.053	0.058	0.025	0.025	0.049	0.063	0.053	0.057	0.025	0.025	0.049	0.063	0.052	0.056	0.025	0.013	0.039	0.050	0.040	0.044	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.005	0.005	0.005	0.005	0.005	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0044	0.0041	0.0043	0.0042	0.0050	0.0050	0.0044	0.0041	0.0043	0.0042	0.0050	0.0050	0.0044	0.0042	0.0043	0.0043	0.0050	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.013	0.014	0.014	0.014	0.006	0.006	0.013	0.014	0.013	0.014	0.006	0.006	0.013	0.014	0.013	0.013	0.006	0.008	0.014	0.015	0.014	0.014	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.0	0.9	1.0	1.0	1.1	1.1	1.0	0.9	1.0	1.0	1.1	1.1	1.0	0.9	1.0	1.0	1.1	1.4	1.2	1.2	1.2	1.2	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.043	0.041	0.043	0.042	0.050	0.050	0.043	0.041	0.043	0.042	0.050	0.050	0.043	0.041	0.043	0.042	0.050	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.05	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0024	0.0032	0.0025	0.0028	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0048	0.0048	0.0048	0.0048	0.0050	0.0050	0.0048	0.0048	0.0048	0.0048	0.0050	0.0050	0.0048	0.0048	0.0048	0.0048	0.0050	0.0001	0.0006	0.0008	0.0007	0.0007	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	8	7	8	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.006	0.005	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.088	0.083	0.086	0.084	0.100	0.100	0.088	0.083	0.086	0.085	0.100	0.100	0.088	0.083	0.087	0.085	0.100	0.002	0.004	0.004	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.013	0.013	0.013	0.013	0.014	0.014	0.013	0.013	0.013	0.013	0.014	0.014	0.013	0.013	0.013	0.013	0.014	0.003	0.004	0.004	0.004	0.004	0.002

- Notes
- 1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.
- 2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.
- 3

Based on the un-ionized portion of ammonia.
- 4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.
- 5

Based on long-term exposure.
- 6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.
- 7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.
- 8

Based on an alkalinity value of less than 60 mg/L.
- 9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).
- 10

Based on the dissolved form of this metal.
- 11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.
- 12

Based on a dissolved saturation of at least 80%.
- 13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.
- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-9 Water Quality Results From Mine Area 5,000 m Downstream of Clarification Pond Outlets (continued)

Sahaviara River 5,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	31	31	30	30	33	33	31	31	30	30	33	33	31	31	30	30	33	45	42	42	41	42	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.16	0.16	0.16	0.16	0.17	0.18	0.16	0.16	0.16	0.16	0.17	0.18	0.16	0.16	0.16	0.16	0.17	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.1	3.1	3.0	3.0	3.2	3.2	3.1	3.1	3.0	3.1	3.2	3.2	3.1	3.1	3.0	3.1	3.2	2.6	2.5	2.5	2.5	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	7	7	7	6	6	7	7	7	7	6	6	7	7	7	7	6	6	7	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.9	0.8	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.8	0.8	0.9	0.8	0.7	0.7	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	2.8	2.7	2.7	2.8	2.7	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0471	0.0468	0.0454	0.0461	0.0498	0.0500	0.0472	0.0469	0.0455	0.0461	0.0498	0.0500	0.0473	0.0469	0.0456	0.0462	0.0498	0.0003	0.0006	0.0006	0.0007	0.0006	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0053	0.0053	0.0052	0.0052	0.0054	0.0055	0.0053	0.0053	0.0052	0.0052	0.0054	0.0055	0.0053	0.0053	0.0052	0.0053	0.0054	0.0002	0.0003	0.0003	0.0004	0.0004	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.032	0.033	0.042	0.037	0.025	0.025	0.032	0.033	0.041	0.037	0.025	0.025	0.032	0.033	0.041	0.037	0.025	0.013	0.021	0.021	0.028	0.024	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0047	0.0047	0.0045	0.0046	0.0050	0.0050	0.0047	0.0047	0.0046	0.0046	0.0050	0.0050	0.0047	0.0047	0.0046	0.0046	0.0050	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.008	0.008	0.009	0.008	0.006	0.006	0.008	0.008	0.008	0.008	0.006	0.006	0.008	0.008	0.008	0.008	0.006	0.008	0.009	0.009	0.010	0.009	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.1	1.0	1.1	1.1	1.4	1.3	1.3	1.3	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.047	0.047	0.045	0.046	0.050	0.050	0.047	0.047	0.045	0.046	0.050	0.050	0.047	0.047	0.045	0.046	0.050	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0011	0.0011	0.0015	0.0013	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0049	0.0048	0.0048	0.0048	0.0050	0.0050	0.0049	0.0048	0.0048	0.0048	0.0050	0.0050	0.0049	0.0048	0.0048	0.0048	0.0050	0.0001	0.0002	0.0002	0.0004	0.0003	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	8	8	8	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.094	0.094	0.091	0.092	0.100	0.100	0.094	0.094	0.091	0.092	0.100	0.100	0.095	0.094	0.091	0.092	0.100	0.002	0.003	0.003	0.003	0.003	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.013	0.013	0.013	0.013	0.014	0.014	0.013	0.013	0.013	0.013	0.014	0.014	0.013	0.013	0.013	0.013	0.014	0.003	0.003	0.003	0.003	0.003	0.002

- Notes
- 1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.
- 2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.
- 3

Based on the un-ionized portion of ammonia.
- 4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.
- 5

Based on long-term exposure.
- 6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.
- 7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.
- 8

Based on an alkalinity value of less than 60 mg/L.
- 9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).
- 10

Based on the dissolved form of this metal.
- 11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.
- 12

Based on a dissolved saturation of at least 80%.
- 13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.
- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-9 Water Quality Results From Mine Area 5,000 m Downstream of Clarification Pond Outlets (continued)

Sahamarirana River 5,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	29	28	29	29	32	33	29	28	29	29	32	33	29	28	29	29	32	45	39	39	40	40	43
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.15	0.15	0.15	0.15	0.17	0.18	0.15	0.15	0.16	0.15	0.17	0.18	0.15	0.15	0.16	0.15	0.17	0.05	0.04	0.04	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.6	1.5	1.6	1.5	1.5	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	2.9	2.9	2.9	2.9	3.1	3.2	2.9	2.9	2.9	2.9	3.1	3.2	2.9	2.9	2.9	2.9	3.1	2.6	2.4	2.4	2.4	2.4	2.5
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	6	6	6	6	7	7	6	6	6	6	7	7	6	6	6	6	7	8	7	7	8	7	8
Potassium (K)	mg/L	-	-	0.9	0.8	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.8	0.8	0.9	0.8	0.7	0.7	0.7	0.7	0.7
Sodium (Na)	mg/L	-	-	1.3	1.4	1.4	1.3	1.3	1.2	1.3	1.4	1.4	1.3	1.3	1.2	1.3	1.4	1.4	1.3	1.3	1.2	2.8	2.6	2.7	2.6	2.6	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2	2	1	1	2	2	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0435	0.0429	0.0447	0.0444	0.0483	0.0500	0.0437	0.0430	0.0448	0.0444	0.0483	0.0500	0.0437	0.0433	0.0450	0.0445	0.0483	0.0003	0.0010	0.0010	0.0009	0.0009	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0050	0.0050	0.0050	0.0050	0.0053	0.0055	0.0050	0.0050	0.0050	0.0050	0.0053	0.0055	0.0050	0.0050	0.0050	0.0050	0.0053	0.0002	0.0005	0.0005	0.0003	0.0003	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.038	0.040	0.031	0.032	0.024	0.025	0.038	0.040	0.031	0.032	0.024	0.025	0.038	0.039	0.030	0.032	0.024	0.013	0.027	0.028	0.019	0.020	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006	0.006	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0044	0.0043	0.0045	0.0044	0.0048	0.0050	0.0044	0.0043	0.0045	0.0044	0.0048	0.0050	0.0044	0.0043	0.0045	0.0044	0.0048	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.012	0.013	0.008	0.007	0.006	0.006	0.012	0.012	0.008	0.007	0.006	0.006	0.012	0.012	0.008	0.007	0.006	0.008	0.013	0.013	0.010	0.009	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.002	0.001	0.001	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.0	1.0	1.0	1.1	1.4	1.2	1.2	1.3	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.043	0.043	0.045	0.044	0.048	0.050	0.043	0.043	0.045	0.044	0.048	0.050	0.043	0.043	0.045	0.044	0.048	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0005	0.0004	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0017	0.0017	0.0010	0.0010	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0046	0.0046	0.0046	0.0046	0.0048	0.0050	0.0047	0.0046	0.0046	0.0046	0.0048	0.0050	0.0047	0.0046	0.0046	0.0046	0.0048	0.0001	0.0004	0.0004	0.0003	0.0003	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	8	8	8	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.087	0.086	0.089	0.089	0.097	0.100	0.087	0.086	0.090	0.089	0.097	0.100	0.087	0.087	0.090	0.089	0.097	0.002	0.003	0.003	0.003	0.003	0.002
Vanadium (V)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.005	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.013	0.013	0.013	0.013	0.013	0.014	0.013	0.013	0.013	0.013	0.013	0.014	0.013	0.013	0.013	0.013	0.013	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-9 Water Quality Results From Mine Area 5,000 m Downstream of Clarification Pond Outlets (continued)

Torotorofotsy River 5,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	33	31	31	31	33	33	33	31	32	31	33	33	33	31	32	31	33	45	45	42	44	43	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.18	0.17	0.17	0.17	0.17	0.18	0.18	0.17	0.17	0.17	0.17	0.18	0.18	0.17	0.17	0.17	0.17	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.2	3.1	3.1	3.1	3.2	3.2	3.2	3.1	3.1	3.1	3.2	3.2	3.2	3.1	3.2	3.1	3.2	2.6	2.6	2.6	2.6	2.6	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.9	0.9	0.8	0.9	0.9	0.9	0.9	0.9	0.8	0.9	0.9	0.9	0.9	0.9	0.8	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	2.8	2.8	2.7	2.7	2.7	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0500	0.0478	0.0481	0.0481	0.0499	0.0500	0.0500	0.0478	0.0483	0.0481	0.0499	0.0500	0.0500	0.0478	0.0487	0.0481	0.0499	0.0003	0.0003	0.0009	0.0008	0.0009	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0055	0.0053	0.0054	0.0054	0.0054	0.0055	0.0055	0.0053	0.0054	0.0054	0.0054	0.0055	0.0055	0.0053	0.0054	0.0054	0.0054	0.0002	0.0002	0.0004	0.0002	0.0003	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.025	0.031	0.029	0.029	0.025	0.025	0.025	0.031	0.028	0.029	0.025	0.025	0.025	0.031	0.027	0.029	0.025	0.013	0.013	0.019	0.014	0.018	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0050	0.0048	0.0048	0.0048	0.0050	0.0050	0.0050	0.0048	0.0048	0.0048	0.0050	0.0050	0.0050	0.0048	0.0049	0.0048	0.0050	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.006	0.018	0.015	0.017	0.006	0.006	0.006	0.018	0.013	0.017	0.006	0.006	0.006	0.018	0.010	0.017	0.006	0.008	0.008	0.019	0.009	0.018	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Iron (Fe)	mg/L	-	-	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.4	1.4	1.3	1.4	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.050	0.048	0.048	0.048	0.050	0.050	0.050	0.048	0.048	0.048	0.050	0.050	0.050	0.048	0.049	0.048	0.050	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0005	0.0011	0.0006	0.0010	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.008	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0001	0.0001	0.0003	0.0001	0.0003	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	9	9	9	9	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.100	0.096	0.096	0.096	0.100	0.100	0.100	0.096	0.097	0.096	0.100	0.100	0.100	0.096	0.097	0.096	0.100	0.002	0.002	0.003	0.003	0.003	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-9 Water Quality Results From Mine Area 5,000 m Downstream of Clarification Pond Outlets (continued)

Torotorofotsy River 5,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	33	31	31	31	33	33	33	31	32	31	33	33	33	31	32	31	33	45	45	42	44	43	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.18	0.17	0.17	0.17	0.17	0.18	0.18	0.17	0.17	0.17	0.17	0.18	0.18	0.17	0.17	0.17	0.17	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.2	3.1	3.1	3.1	3.2	3.2	3.2	3.1	3.1	3.1	3.2	3.2	3.2	3.1	3.2	3.1	3.2	2.6	2.6	2.6	2.6	2.6	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.9	0.9	0.8	0.9	0.9	0.9	0.9	0.9	0.8	0.9	0.9	0.9	0.9	0.9	0.8	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	2.8	2.8	2.7	2.7	2.7	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0500	0.0478	0.0481	0.0481	0.0499	0.0500	0.0500	0.0478	0.0483	0.0481	0.0499	0.0500	0.0500	0.0478	0.0487	0.0481	0.0499	0.0003	0.0003	0.0009	0.0008	0.0009	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0055	0.0053	0.0054	0.0054	0.0054	0.0055	0.0055	0.0053	0.0054	0.0054	0.0054	0.0055	0.0055	0.0053	0.0054	0.0054	0.0054	0.0002	0.0002	0.0004	0.0002	0.0003	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.025	0.031	0.029	0.029	0.025	0.025	0.025	0.031	0.028	0.029	0.025	0.025	0.025	0.031	0.027	0.029	0.025	0.013	0.013	0.019	0.014	0.018	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0050	0.0048	0.0048	0.0048	0.0050	0.0050	0.0050	0.0048	0.0048	0.0048	0.0050	0.0050	0.0050	0.0048	0.0049	0.0048	0.0050	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.006	0.018	0.015	0.017	0.006	0.006	0.006	0.018	0.013	0.017	0.006	0.006	0.006	0.018	0.010	0.017	0.006	0.008	0.008	0.019	0.009	0.018	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Iron (Fe)	mg/L	-	-	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.4	1.4	1.3	1.4	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.050	0.048	0.048	0.048	0.050	0.050	0.050	0.048	0.048	0.048	0.050	0.050	0.050	0.048	0.049	0.048	0.050	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0005	0.0011	0.0006	0.0010	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.008	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0001	0.0001	0.0003	0.0001	0.0003	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	9	9	9	9	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.100	0.096	0.096	0.096	0.100	0.100	0.100	0.096	0.097	0.096	0.100	0.100	0.100	0.096	0.097	0.096	0.100	0.002	0.002	0.003	0.003	0.003	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-9 Water Quality Results From Mine Area 5,000 m Downstream of Clarification Pond Outlets (continued)

Ankaja River 5,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	29	29	30	29	32	33	29	29	30	29	32	33	29	29	30	29	32	45	40	40	42	39	43
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.15	0.15	0.15	0.15	0.17	0.18	0.15	0.15	0.16	0.15	0.17	0.18	0.15	0.15	0.16	0.15	0.17	0.05	0.04	0.04	0.05	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.6	1.6	1.5	1.5	1.5	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.0	3.0	3.0	3.0	3.1	3.2	3.0	3.0	3.0	3.0	3.1	3.2	3.0	3.0	3.0	3.0	3.1	2.6	2.5	2.4	2.5	2.4	2.5
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	6	6	6	6	7	7	6	6	6	6	7	7	6	6	6	6	7	8	7	7	8	7	8
Potassium (K)	mg/L	-	-	0.9	0.8	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.8	0.8	0.9	0.8	0.7	0.7	0.7	0.7	0.7
Sodium (Na)	mg/L	-	-	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.2	1.2	1.2	1.2	1.2	2.8	2.5	2.5	2.6	2.5	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2	2	1	1	2	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0448	0.0447	0.0451	0.0447	0.0484	0.0500	0.0448	0.0450	0.0453	0.0447	0.0484	0.0500	0.0448	0.0450	0.0455	0.0447	0.0484	0.0003	0.0013	0.0013	0.0012	0.0015	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0051	0.0051	0.0051	0.0051	0.0053	0.0055	0.0051	0.0051	0.0051	0.0051	0.0053	0.0055	0.0051	0.0051	0.0051	0.0051	0.0053	0.0002	0.0005	0.0004	0.0002	0.0005	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.033	0.033	0.032	0.033	0.024	0.025	0.033	0.032	0.031	0.033	0.024	0.025	0.033	0.032	0.030	0.033	0.024	0.013	0.022	0.021	0.012	0.022	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006	0.006	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0045	0.0045	0.0045	0.0045	0.0048	0.0050	0.0045	0.0045	0.0045	0.0045	0.0048	0.0050	0.0045	0.0045	0.0045	0.0045	0.0048	0.0005	0.0005	0.0005	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.026	0.024	0.024	0.027	0.006	0.006	0.026	0.022	0.023	0.027	0.006	0.006	0.026	0.022	0.021	0.027	0.006	0.008	0.027	0.023	0.007	0.029	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.005	0.004	0.005	0.005	0.004	0.004	0.005	0.004	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.005	0.004	0.005	0.005	0.004	0.005	0.005	0.004	0.005	0.005	0.004	0.005	0.005	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.0	1.0	1.0	1.1	1.4	1.3	1.3	1.3	1.2	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.045	0.044	0.045	0.044	0.048	0.050	0.045	0.045	0.045	0.044	0.048	0.050	0.045	0.045	0.045	0.044	0.048	0.005	0.005	0.005	0.006	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.07	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0004	0.0005	0.0004	0.0005	0.0005	0.0005	0.0005	0.0005	0.0004	0.0005	0.0005	0.0005	0.0005	0.0005	0.0004	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0015	0.0013	0.0005	0.0015	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0047	0.0047	0.0047	0.0047	0.0048	0.0050	0.0047	0.0047	0.0047	0.0047	0.0048	0.0050	0.0047	0.0047	0.0047	0.0047	0.0048	0.0001	0.0004	0.0004	0.0002	0.0004	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	8	8	8	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.090	0.089	0.090	0.089	0.097	0.100	0.090	0.090	0.091	0.089	0.097	0.100	0.090	0.090	0.091	0.089	0.097	0.002	0.004	0.004	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.013	0.013	0.013	0.013	0.013	0.014	0.013	0.013	0.013	0.013	0.013	0.014	0.013	0.013	0.013	0.013	0.013	0.003	0.003	0.003	0.002	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-9 Water Quality Results From Mine Area 5,000 m Downstream of Clarification Pond Outlets (continued)

Antsahalava River 5,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	39	37	39	38	44	45	39	37	39	38	44	45	39	37	39	38	44	45	39	37	39	38	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	7	7	7	8	8	7	7	7	7	8	8	7	7	7	7	8	8	7	7	7	7	8
Potassium (K)	mg/L	-	-	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	2.8	2.8	2.9	2.8	2.8	2.7	2.8	2.8	2.9	2.8	2.8	2.7	2.8	2.8	2.9	2.8	2.8	2.7	2.8	2.8	2.9	2.8	2.8	2.7
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0013	0.0015	0.0014	0.0015	0.0003	0.0003	0.0013	0.0015	0.0014	0.0015	0.0003	0.0003	0.0013	0.0015	0.0014	0.0015	0.0003	0.0003	0.0013	0.0015	0.0014	0.0015	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0007	0.0009	0.0007	0.0008	0.0002	0.0002	0.0007	0.0009	0.0007	0.0008	0.0002	0.0002	0.0007	0.0009	0.0007	0.0008	0.0002	0.0002	0.0007	0.0009	0.0007	0.0008	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.039	0.050	0.040	0.044	0.013	0.013	0.039	0.050	0.040	0.044	0.013	0.013	0.039	0.050	0.040	0.044	0.013	0.013	0.039	0.050	0.040	0.044	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.014	0.015	0.014	0.014	0.008	0.008	0.014	0.015	0.014	0.014	0.008	0.008	0.014	0.015	0.014	0.014	0.008	0.008	0.014	0.015	0.014	0.014	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.2	1.2	1.2	1.2	1.4	1.4	1.2	1.2	1.2	1.2	1.4	1.4	1.2	1.2	1.2	1.2	1.4	1.4	1.2	1.2	1.2	1.2	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0024	0.0032	0.0025	0.0028	0.0005	0.0005	0.0024	0.0032	0.0025	0.0028	0.0005	0.0005	0.0024	0.0032	0.0025	0.0028	0.0005	0.0005	0.0024	0.0032	0.0025	0.0028	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0006	0.0008	0.0007	0.0007	0.0001	0.0001	0.0006	0.0008	0.0007	0.0007	0.0001	0.0001	0.0006	0.0008	0.0007	0.0007	0.0001	0.0001	0.0006	0.0008	0.0007	0.0007	0.0001
Silicon (Si)	mg/L	-	-	9	8	7	8	8	9	9	8	7	8	8	9	9	8	7	8	8	9	9	8	7	8	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.006	0.005	0.006	0.004	0.005	0.005	0.006	0.005	0.006	0.004	0.005	0.005	0.006	0.005	0.006	0.004	0.005	0.005	0.006	0.005	0.006	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.004	0.004	0.004	0.004	0.002	0.003	0.004	0.004	0.004	0.004	0.002	0.003	0.004	0.004	0.004	0.004	0.002	0.003	0.004	0.004	0.004	0.004	0.002

- Notes
- 1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.
- 2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.
- 3

Based on the un-ionized portion of ammonia.
- 4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.
- 5

Based on long-term exposure.
- 6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.
- 7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.
- 8

Based on an alkalinity value of less than 60 mg/L.
- 9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).
- 10

Based on the dissolved form of this metal.
- 11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.
- 12

Based on a dissolved saturation of at least 80%.
- 13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.
- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-9 Water Quality Results From Mine Area 5,000 m Downstream of Clarification Pond Outlets (continued)

Sahaviara River 5,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	42	42	41	42	44	45	42	42	41	42	44	45	42	42	41	42	44	45	42	42	41	42	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7
Sulphate (SO ₄)	mg/L	-	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0006	0.0006	0.0007	0.0006	0.0003	0.0003	0.0006	0.0006	0.0007	0.0006	0.0003	0.0003	0.0006	0.0006	0.0007	0.0006	0.0003	0.0003	0.0006	0.0006	0.0007	0.0006	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0003	0.0003	0.0004	0.0004	0.0002	0.0002	0.0003	0.0003	0.0004	0.0004	0.0002	0.0002	0.0003	0.0003	0.0004	0.0004	0.0002	0.0002	0.0003	0.0003	0.0004	0.0004	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.021	0.021	0.028	0.024	0.013	0.013	0.021	0.021	0.028	0.024	0.013	0.013	0.021	0.021	0.028	0.024	0.013	0.013	0.021	0.021	0.028	0.024	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.009	0.009	0.010	0.009	0.008	0.008	0.009	0.009	0.010	0.009	0.008	0.008	0.009	0.009	0.010	0.009	0.008	0.008	0.009	0.009	0.010	0.009	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0011	0.0011	0.0015	0.0013	0.0005	0.0005	0.0011	0.0011	0.0015	0.0013	0.0005	0.0005	0.0011	0.0011	0.0015	0.0013	0.0005	0.0005	0.0011	0.0011	0.0015	0.0013	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0002	0.0002	0.0004	0.0003	0.0001	0.0001	0.0002	0.0002	0.0004	0.0003	0.0001	0.0001	0.0002	0.0002	0.0004	0.0003	0.0001	0.0001	0.0002	0.0002	0.0004	0.0003	0.0001
Silicon (Si)	mg/L	-	-	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-9 Water Quality Results From Mine Area 5,000 m Downstream of Clarification Pond Outlets (continued)

Sahamarirana River 5,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	39	39	40	40	43	45	39	39	40	40	43	45	39	39	40	40	43	45	39	39	40	40	43
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.6	1.5	1.5	1.6	1.6	1.5	1.6	1.5	1.5	1.6	1.6	1.5	1.6	1.5	1.5	1.6	1.6	1.5	1.6	1.5	1.6	
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
Chloride (Cl)	mg/L	-	-	2.6	2.4	2.4	2.4	2.4	2.5	2.6	2.4	2.4	2.4	2.4	2.5	2.6	2.4	2.4	2.4	2.4	2.5	2.6	2.4	2.4	2.4	2.4	2.5
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	8	7	7	8	7	8	8	7	7	8	7	8	8	7	7	8	7	8	8	7	7	8	7	8
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	
Sodium (Na)	mg/L	-	-	2.8	2.6	2.7	2.6	2.6	2.7	2.8	2.6	2.7	2.6	2.6	2.7	2.8	2.6	2.7	2.6	2.6	2.7	2.8	2.6	2.7	2.6	2.6	2.7
Sulphate (SO ₄)	mg/L	-	-	1	2	2	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0010	0.0010	0.0009	0.0009	0.0003	0.0003	0.0010	0.0010	0.0009	0.0009	0.0003	0.0003	0.0010	0.0010	0.0009	0.0009	0.0003	0.0003	0.0010	0.0010	0.0009	0.0009	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0005	0.0005	0.0003	0.0003	0.0002	0.0002	0.0005	0.0005	0.0003	0.0003	0.0002	0.0002	0.0005	0.0005	0.0003	0.0003	0.0002	0.0002	0.0005	0.0005	0.0003	0.0003	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.027	0.028	0.019	0.020	0.013	0.013	0.027	0.028	0.019	0.020	0.013	0.013	0.027	0.028	0.019	0.020	0.013	0.013	0.027	0.028	0.019	0.020	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.013	0.013	0.010	0.009	0.008	0.008	0.013	0.013	0.010	0.009	0.008	0.008	0.013	0.013	0.010	0.009	0.008	0.008	0.013	0.013	0.010	0.009	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.002	0.002	0.002	0.002	0.001	0.001	0.002	0.002	0.002	0.002	0.001	0.001	0.002	0.002	0.002	0.002	0.001	0.001	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.2	1.2	1.3	1.3	1.4	1.4	1.2	1.2	1.3	1.3	1.4	1.4	1.2	1.2	1.3	1.3	1.4	1.4	1.2	1.2	1.3	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0017	0.0017	0.0010	0.0010	0.0005	0.0005	0.0017	0.0017	0.0010	0.0010	0.0005	0.0005	0.0017	0.0017	0.0010	0.0010	0.0005	0.0005	0.0017	0.0017	0.0010	0.0010	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0004	0.0004	0.0003	0.0003	0.0001	0.0001	0.0004	0.0004	0.0003	0.0003	0.0001	0.0001	0.0004	0.0004	0.0003	0.0003	0.0001	0.0001	0.0004	0.0004	0.0003	0.0003	0.0001
Silicon (Si)	mg/L	-	-	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-9 Water Quality Results From Mine Area 5,000 m Downstream of Clarification Pond Outlets (continued)

Torotorofotsy River 5,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	42	44	43	44	45	45	42	44	43	44	45	45	42	44	43	44	45	45	42	44	43	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.8	
Sodium (Na)	mg/L	-	-	2.8	2.8	2.7	2.7	2.7	2.7	2.8	2.8	2.7	2.7	2.7	2.7	2.8	2.8	2.7	2.7	2.7	2.7	2.8	2.8	2.7	2.7	2.7	
Sulphate (SO ₄)	mg/L	-	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0009	0.0008	0.0009	0.0003	0.0003	0.0003	0.0009	0.0008	0.0009	0.0003	0.0003	0.0003	0.0009	0.0008	0.0009	0.0003	0.0003	0.0003	0.0009	0.0008	0.0009	
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0004	0.0002	0.0003	0.0002	0.0002	0.0002	0.0004	0.0002	0.0003	0.0002	0.0002	0.0002	0.0004	0.0002	0.0003	0.0002	0.0002	0.0002	0.0004	0.0002	0.0003	
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.019	0.014	0.018	0.013	0.013	0.013	0.019	0.014	0.018	0.013	0.013	0.013	0.019	0.014	0.018	0.013	0.013	0.013	0.019	0.014	0.018	
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.019	0.009	0.018	0.008	0.008	0.008	0.019	0.009	0.018	0.008	0.008	0.008	0.019	0.009	0.018	0.008	0.008	0.008	0.019	0.009	0.018	
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	
Iron (Fe)	mg/L	-	-	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.3	
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0011	0.0006	0.0010	0.0005	0.0005	0.0005	0.0011	0.0006	0.0010	0.0005	0.0005	0.0005	0.0011	0.0006	0.0010	0.0005	0.0005	0.0005	0.0011	0.0006	0.0010	
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.008	
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0003	0.0001	0.0003	0.0001	0.0001	0.0001	0.0003	0.0001	0.0003	0.0001	0.0001	0.0001	0.0003	0.0001	0.0003	0.0001	0.0001	0.0001	0.0003	0.0001	0.0003	
Silicon (Si)	mg/L	-	-	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.004	
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.003	0.003	0.003	0.002	0.002	0.002	0.003	0.003	0.003	0.002	0.002	0.002	0.003	0.003	0.003	0.002	0.002	0.002	0.003	0.003	0.003	
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.002	

- Notes
- 1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.
- 2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.
- 3

Based on the un-ionized portion of ammonia.
- 4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.
- 5

Based on long-term exposure.
- 6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.
- 7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.
- 8

Based on an alkalinity value of less than 60 mg/L.
- 9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).
- 10

Based on the dissolved form of this metal.
- 11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.
- 12

Based on a dissolved saturation of at least 80%.
- 13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.
- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-9 Water Quality Results From Mine Area 5,000 m Downstream of Clarification Pond Outlets (continued)

Sakalava River 5,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	43	41	43	44	45	45	43	41	43	44	45	45	43	41	43	44	45	45	43	41	43	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.6	2.5	2.6	2.6	2.6	2.6	2.6	2.5	2.6	2.6	2.6	2.6	2.6	2.5	2.6	2.6	2.6	2.6	2.6	2.5	2.6	
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.8	
Sodium (Na)	mg/L	-	-	2.8	2.8	2.7	2.6	2.7	2.7	2.8	2.8	2.7	2.6	2.7	2.7	2.8	2.8	2.7	2.6	2.7	2.7	2.8	2.8	2.7	2.6	2.7	
Sulphate (SO ₄)	mg/L	-	-	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0010	0.0010	0.0008	0.0003	0.0003	0.0003	0.0010	0.0010	0.0008	0.0003	0.0003	0.0003	0.0010	0.0010	0.0008	0.0003	0.0003	0.0003	0.0010	0.0010	0.0008	
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0002	0.0004	0.0002	0.0002	0.0002	0.0002	0.0002	0.0004	0.0002	0.0002	0.0002	0.0002	0.0002	0.0004	0.0002	0.0002	0.0002	0.0002	0.0004	0.0002	0.0002	
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.013	0.021	0.013	0.013	0.013	0.013	0.013	0.021	0.013	0.013	0.013	0.013	0.013	0.021	0.013	0.013	0.013	0.013	0.013	0.021	0.013	
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.008	0.025	0.008	0.008	0.008	0.008	0.008	0.025	0.008	0.008	0.008	0.008	0.008	0.025	0.008	0.008	0.008	0.008	0.008	0.025	0.008	
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	
Iron (Fe)	mg/L	-	-	1.4	1.4	1.4	1.3	1.4	1.4	1.4	1.4	1.4	1.3	1.4	1.4	1.4	1.4	1.4	1.3	1.4	1.4	1.4	1.4	1.4	1.3	1.4	
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0005	0.0013	0.0005	0.0005	0.0005	0.0005	0.0005	0.0013	0.0005	0.0005	0.0005	0.0005	0.0005	0.0013	0.0005	0.0005	0.0005	0.0005	0.0005	0.0013	0.0005	
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.008	0.007	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.008	0.008	0.008	0.008	0.007	0.008	
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0002	0.0003	0.0001	0.0001	0.0001	0.0001	0.0002	0.0003	0.0001	0.0001	0.0001	0.0001	0.0002	0.0003	0.0001	0.0001	0.0001	0.0001	0.0002	0.0003	0.0001	
Silicon (Si)	mg/L	-	-	9	9	9	8	9	9	9	9	9	8	9	9	9	9	9	8	9	9	9	9	9	8	9	
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.004	
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.003	0.003	0.003	0.002	0.002	0.002	0.003	0.003	0.003	0.002	0.002	0.002	0.003	0.003	0.003	0.002	0.002	0.002	0.003	0.003	0.002	
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	

- Notes
- 1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.
- 2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.
- 3

Based on the un-ionized portion of ammonia.
- 4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.
- 5

Based on long-term exposure.
- 6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.
- 7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.
- 8

Based on an alkalinity value of less than 60 mg/L.
- 9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).
- 10

Based on the dissolved form of this metal.
- 11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.
- 12

Based on a dissolved saturation of at least 80%.
- 13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.
- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-9 Water Quality Results From Mine Area 5,000 m Downstream of Clarification Pond Outlets (continued)

Ankaja River 5,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	40	40	42	39	43	45	40	40	42	39	43	45	40	40	42	39	43	45	40	40	42	39	43
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.5	1.5	1.5	1.6	1.6	1.6	1.5	1.5	1.5	1.6	1.6	1.6	1.5	1.5	1.5	1.6	1.6	1.6	1.5	1.5	1.5	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.5	2.4	2.5	2.4	2.5	2.6	2.5	2.4	2.5	2.4	2.5	2.6	2.5	2.4	2.5	2.4	2.5	2.6	2.5	2.4	2.5	2.4	2.5
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	7	8	7	8	8	7	7	8	7	8	8	7	7	8	7	8	8	7	7	8	7	8
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7
Sodium (Na)	mg/L	-	-	2.8	2.5	2.5	2.6	2.5	2.7	2.8	2.5	2.5	2.6	2.5	2.7	2.8	2.5	2.5	2.6	2.5	2.7	2.8	2.5	2.5	2.6	2.5	2.7
Sulphate (SO ₄)	mg/L	-	-	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0013	0.0013	0.0012	0.0015	0.0003	0.0003	0.0013	0.0013	0.0012	0.0015	0.0003	0.0003	0.0013	0.0013	0.0012	0.0015	0.0003	0.0003	0.0013	0.0013	0.0012	0.0015	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0005	0.0004	0.0002	0.0005	0.0002	0.0002	0.0005	0.0004	0.0002	0.0005	0.0002	0.0002	0.0005	0.0004	0.0002	0.0005	0.0002	0.0002	0.0005	0.0004	0.0002	0.0005	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.022	0.021	0.012	0.022	0.013	0.013	0.022	0.021	0.012	0.022	0.013	0.013	0.022	0.021	0.012	0.022	0.013	0.013	0.022	0.021	0.012	0.022	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0006	0.0006	0.0005	0.0005	0.0005	0.0005	0.0006	0.0006	0.0005	0.0005	0.0005	0.0005	0.0006	0.0006	0.0005	0.0005	0.0005	0.0005	0.0006	0.0006	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.027	0.023	0.007	0.029	0.008	0.008	0.027	0.023	0.007	0.029	0.008	0.008	0.027	0.023	0.007	0.029	0.008	0.008	0.027	0.023	0.007	0.029	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.3	1.3	1.3	1.2	1.4	1.4	1.3	1.3	1.3	1.2	1.4	1.4	1.3	1.3	1.3	1.2	1.4	1.4	1.3	1.3	1.3	1.2	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0015	0.0013	0.0005	0.0015	0.0005	0.0005	0.0015	0.0013	0.0005	0.0015	0.0005	0.0005	0.0015	0.0013	0.0005	0.0015	0.0005	0.0005	0.0015	0.0013	0.0005	0.0015	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0004	0.0004	0.0002	0.0004	0.0001	0.0001	0.0004	0.0004	0.0002	0.0004	0.0001	0.0001	0.0004	0.0004	0.0002	0.0004	0.0001	0.0001	0.0004	0.0004	0.0002	0.0004	0.0001
Silicon (Si)	mg/L	-	-	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-9 Water Quality Results From Mine Area 5,000 m Downstream of Clarification Pond Outlets (continued)

Antsahalava River 5,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	39	37	39	38	44	45	39	37	39	38	44	45	39	37	39	38	44	33	29	27	28	28	33
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.18	0.15	0.14	0.15	0.14	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.4	1.4	1.5	1.4	1.4	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	3.2	3.0	2.9	3.0	2.9	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	7	7	7	8	8	7	7	7	7	8	8	7	7	7	7	8	7	6	6	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.8	0.7	0.6	0.7	0.7	0.8	0.9	0.8	0.7	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.8	2.9	2.8	2.8	2.7	2.8	2.8	2.9	2.8	2.8	2.7	2.8	2.8	2.9	2.8	2.8	2.7	1.3	1.5	1.7	1.6	1.6	1.3
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0013	0.0015	0.0014	0.0015	0.0003	0.0003	0.0013	0.0015	0.0014	0.0015	0.0003	0.0003	0.0013	0.0015	0.0014	0.0015	0.0003	0.0500	0.0439	0.0415	0.0432	0.0424	0.0498
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0007	0.0009	0.0007	0.0008	0.0002	0.0002	0.0007	0.0009	0.0007	0.0008	0.0002	0.0002	0.0007	0.0009	0.0007	0.0008	0.0002	0.0055	0.0052	0.0052	0.0052	0.0052	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.039	0.050	0.040	0.044	0.013	0.013	0.039	0.050	0.040	0.044	0.013	0.013	0.039	0.050	0.040	0.044	0.013	0.025	0.049	0.063	0.053	0.057	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.007	0.006	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0044	0.0041	0.0043	0.0042	0.0050
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.014	0.015	0.014	0.014	0.008	0.008	0.014	0.015	0.014	0.014	0.008	0.008	0.014	0.015	0.014	0.014	0.008	0.006	0.013	0.014	0.013	0.014	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.005	0.004	0.004	0.004	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.2	1.2	1.2	1.2	1.4	1.4	1.2	1.2	1.2	1.2	1.4	1.4	1.2	1.2	1.2	1.2	1.4	1.1	1.0	0.9	1.0	1.0	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.043	0.041	0.043	0.042	0.050
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0024	0.0032	0.0025	0.0028	0.0005	0.0005	0.0024	0.0032	0.0025	0.0028	0.0005	0.0005	0.0024	0.0032	0.0025	0.0028	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0006	0.0008	0.0007	0.0007	0.0001	0.0001	0.0006	0.0008	0.0007	0.0007	0.0001	0.0001	0.0006	0.0008	0.0007	0.0007	0.0001	0.0050	0.0048	0.0048	0.0048	0.0048	0.0050
Silicon (Si)	mg/L	-	-	9	8	7	8	8	9	9	8	7	8	8	9	9	8	7	8	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.006	0.005	0.006	0.004	0.005	0.005	0.006	0.005	0.006	0.004	0.005	0.005	0.006	0.005	0.006	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.100	0.088	0.083	0.086	0.085	0.100
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.004	0.004	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.004	0.004	0.004	0.004	0.002	0.003	0.004	0.004	0.004	0.004	0.002	0.003	0.004	0.004	0.004	0.004	0.002	0.014	0.013	0.013	0.013	0.013	0.014

- Notes
- 1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.
- 2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.
- 3

Based on the un-ionized portion of ammonia.
- 4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.
- 5

Based on long-term exposure.
- 6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.
- 7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.
- 8

Based on an alkalinity value of less than 60 mg/L.
- 9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).
- 10

Based on the dissolved form of this metal.
- 11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.
- 12

Based on a dissolved saturation of at least 80%.
- 13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.
- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-9 Water Quality Results From Mine Area 5,000 m Downstream of Clarification Pond Outlets (continued)

Sahaviara River 5,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	42	42	41	42	44	45	42	42	41	42	44	45	42	42	41	42	44	33	31	31	30	30	33
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.18	0.16	0.16	0.16	0.16	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.4	1.4	1.4	1.4	1.4	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	3.2	3.1	3.1	3.0	3.1	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7	7	7	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.9	0.8	0.8	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	1.3	1.3	1.3	1.4	1.4	1.3
Sulphate (SO ₄)	mg/L	-	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0006	0.0006	0.0007	0.0006	0.0003	0.0003	0.0006	0.0006	0.0007	0.0006	0.0003	0.0003	0.0006	0.0006	0.0007	0.0006	0.0003	0.0500	0.0472	0.0469	0.0455	0.0461	0.0498
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0003	0.0003	0.0004	0.0004	0.0002	0.0002	0.0003	0.0003	0.0004	0.0004	0.0002	0.0002	0.0003	0.0003	0.0004	0.0004	0.0002	0.0055	0.0053	0.0053	0.0052	0.0053	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.021	0.021	0.028	0.024	0.013	0.013	0.021	0.021	0.028	0.024	0.013	0.013	0.021	0.021	0.028	0.024	0.013	0.025	0.032	0.033	0.041	0.037	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.006	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0047	0.0047	0.0046	0.0046	0.0050
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.009	0.009	0.010	0.009	0.008	0.008	0.009	0.009	0.010	0.009	0.008	0.008	0.009	0.009	0.010	0.009	0.008	0.006	0.008	0.008	0.008	0.008	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Iron (Fe)	mg/L	-	-	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.1	1.1	1.1	1.0	1.1	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.047	0.047	0.045	0.046	0.050
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0011	0.0011	0.0015	0.0013	0.0005	0.0005	0.0011	0.0011	0.0015	0.0013	0.0005	0.0005	0.0011	0.0011	0.0015	0.0013	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0002	0.0002	0.0004	0.0003	0.0001	0.0001	0.0002	0.0002	0.0004	0.0003	0.0001	0.0001	0.0002	0.0002	0.0004	0.0003	0.0001	0.0050	0.0049	0.0048	0.0048	0.0048	0.0050
Silicon (Si)	mg/L	-	-	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.100	0.094	0.094	0.091	0.092	0.100
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.014	0.013	0.013	0.013	0.013	0.014

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-9 Water Quality Results From Mine Area 5,000 m Downstream of Clarification Pond Outlets (continued)

Sahamarirana River 5,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	39	39	40	40	43	45	39	39	40	40	43	45	39	39	40	40	43	33	29	28	29	29	32
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.18	0.15	0.15	0.16	0.15	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.5	1.6	1.5	1.5	1.6	1.6	1.5	1.6	1.5	1.5	1.6	1.6	1.5	1.6	1.5	1.5	1.6	1.4	1.3	1.3	1.3	1.3	1.3
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.4	2.4	2.4	2.4	2.5	2.6	2.4	2.4	2.4	2.4	2.5	2.6	2.4	2.4	2.4	2.4	2.5	3.2	2.9	2.9	2.9	2.9	3.1
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	8	7	7	8	7	8	8	7	7	8	7	8	8	7	7	8	7	8	7	6	6	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.9	0.8	0.8	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.6	2.7	2.6	2.6	2.7	2.8	2.6	2.7	2.6	2.6	2.7	2.8	2.6	2.7	2.6	2.6	2.7	1.3	1.4	1.4	1.3	1.3	1.2
Sulphate (SO ₄)	mg/L	-	-	1	2	2	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1	2	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0010	0.0010	0.0009	0.0009	0.0003	0.0003	0.0010	0.0010	0.0009	0.0009	0.0003	0.0003	0.0010	0.0010	0.0009	0.0009	0.0003	0.0500	0.0437	0.0431	0.0448	0.0444	0.0483
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0005	0.0005	0.0003	0.0003	0.0002	0.0002	0.0005	0.0005	0.0003	0.0003	0.0002	0.0002	0.0005	0.0005	0.0003	0.0003	0.0002	0.0055	0.0050	0.0050	0.0050	0.0050	0.0053
Barium (Ba)	mg/L	0.7	-	0.013	0.027	0.028	0.019	0.020	0.013	0.013	0.027	0.028	0.019	0.020	0.013	0.013	0.027	0.028	0.019	0.020	0.013	0.025	0.038	0.040	0.031	0.032	0.024
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.006	0.006	0.006	0.006	0.006
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0044	0.0043	0.0045	0.0044	0.0048
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.013	0.013	0.010	0.009	0.008	0.008	0.013	0.013	0.010	0.009	0.008	0.008	0.013	0.013	0.010	0.009	0.008	0.006	0.012	0.012	0.008	0.007	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.002	0.002	0.002	0.002	0.001	0.001	0.002	0.002	0.002	0.002	0.001	0.001	0.002	0.002	0.002	0.005	0.004	0.004	0.004	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.2	1.2	1.3	1.3	1.4	1.4	1.2	1.2	1.3	1.3	1.4	1.4	1.2	1.2	1.3	1.3	1.4	1.1	1.0	1.0	1.0	1.0	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.043	0.043	0.045	0.044	0.048
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0017	0.0017	0.0010	0.0010	0.0005	0.0005	0.0017	0.0017	0.0010	0.0010	0.0005	0.0005	0.0017	0.0017	0.0010	0.0010	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0004	0.0004	0.0003	0.0003	0.0001	0.0001	0.0004	0.0004	0.0003	0.0003	0.0001	0.0001	0.0004	0.0004	0.0003	0.0003	0.0001	0.0050	0.0047	0.0046	0.0046	0.0046	0.0048
Silicon (Si)	mg/L	-	-	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.100	0.087	0.086	0.090	0.089	0.097
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.004	0.004	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.014	0.013	0.013	0.013	0.013	0.013

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-9 Water Quality Results From Mine Area 5,000 m Downstream of Clarification Pond Outlets (continued)

Torotorofotsy River 5,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	42	44	43	44	45	45	42	44	43	44	45	45	42	44	43	44	33	33	31	32	31	33
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.18	0.18	0.17	0.17	0.17	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.4	1.4	1.4	1.4	1.4	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	3.2	3.2	3.1	3.1	3.1	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7	7	7	7	7	7
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.9	0.9	0.8	0.9	0.9	0.9
Sodium (Na)	mg/L	-	-	2.8	2.8	2.7	2.7	2.7	2.7	2.8	2.8	2.7	2.7	2.7	2.7	2.8	2.8	2.7	2.7	2.7	2.7	1.3	1.3	1.3	1.3	1.3	1.3
Sulphate (SO ₄)	mg/L	-	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0009	0.0008	0.0009	0.0003	0.0003	0.0003	0.0009	0.0008	0.0009	0.0003	0.0003	0.0003	0.0009	0.0008	0.0009	0.0003	0.0500	0.0500	0.0478	0.0483	0.0481	0.0499
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0004	0.0002	0.0003	0.0002	0.0002	0.0002	0.0004	0.0002	0.0003	0.0002	0.0002	0.0002	0.0004	0.0002	0.0003	0.0002	0.0055	0.0055	0.0053	0.0054	0.0054	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.019	0.014	0.018	0.013	0.013	0.013	0.019	0.014	0.018	0.013	0.013	0.013	0.019	0.014	0.018	0.013	0.025	0.025	0.031	0.028	0.029	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.007	0.007	0.007	0.007	0.007	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0050	0.0048	0.0048	0.0048	0.0050
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.019	0.009	0.018	0.008	0.008	0.008	0.019	0.009	0.018	0.008	0.008	0.008	0.019	0.009	0.018	0.008	0.006	0.006	0.018	0.013	0.017	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.4	1.4	1.4	1.3	1.4	1.3	1.4	1.1	1.1	1.1	1.1	1.1	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.050	0.048	0.048	0.048	0.050
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0011	0.0006	0.0010	0.0005	0.0005	0.0005	0.0011	0.0006	0.0010	0.0005	0.0005	0.0005	0.0011	0.0006	0.0010	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0003	0.0001	0.0003	0.0001	0.0001	0.0001	0.0003	0.0001	0.0003	0.0001	0.0001	0.0001	0.0003	0.0001	0.0003	0.0001	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050
Silicon (Si)	mg/L	-	-	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.004	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.003	0.003	0.003	0.002	0.002	0.002	0.003	0.003	0.003	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.100	0.100	0.096	0.097	0.096	0.100
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.014	0.014	0.013	0.013	0.013	0.014

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-9 Water Quality Results From Mine Area 5,000 m Downstream of Clarification Pond Outlets (continued)

Sakalava River 5,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	43	41	43	44	45	45	43	41	43	44	45	45	43	41	43	44	33	33	31	31	31	33
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.18	0.18	0.17	0.16	0.17	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.4	1.4	1.4	1.4	1.4	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.6	2.5	2.6	2.6	2.6	2.6	2.6	2.5	2.6	2.6	2.6	2.6	2.6	2.5	2.6	2.6	3.2	3.2	3.1	3.1	3.1	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7	7	7	7	7	7
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.9	0.9	0.9	0.8	0.9	0.9
Sodium (Na)	mg/L	-	-	2.8	2.8	2.7	2.6	2.7	2.7	2.8	2.8	2.7	2.6	2.7	2.7	2.8	2.8	2.7	2.6	2.7	2.7	1.3	1.3	1.3	1.3	1.3	1.3
Sulphate (SO ₄)	mg/L	-	-	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0010	0.0010	0.0008	0.0003	0.0003	0.0003	0.0010	0.0010	0.0008	0.0003	0.0003	0.0003	0.0010	0.0010	0.0008	0.0003	0.0500	0.0500	0.0478	0.0468	0.0481	0.0497
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0002	0.0004	0.0002	0.0002	0.0002	0.0002	0.0002	0.0004	0.0002	0.0002	0.0002	0.0002	0.0002	0.0004	0.0002	0.0002	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.013	0.021	0.013	0.013	0.013	0.013	0.013	0.021	0.013	0.013	0.013	0.013	0.013	0.021	0.013	0.013	0.025	0.025	0.028	0.032	0.027	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.007	0.007	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0050	0.0048	0.0047	0.0048	0.0050
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.008	0.025	0.008	0.008	0.008	0.008	0.008	0.025	0.008	0.008	0.008	0.008	0.008	0.025	0.008	0.008	0.006	0.006	0.014	0.023	0.011	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.4	1.3	1.4	1.4	1.4	1.4	1.4	1.3	1.4	1.4	1.4	1.4	1.4	1.3	1.4	1.4	1.1	1.1	1.1	1.1	1.1	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.050	0.048	0.047	0.048	0.050
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0005	0.0013	0.0005	0.0005	0.0005	0.0005	0.0005	0.0013	0.0005	0.0005	0.0005	0.0005	0.0005	0.0013	0.0005	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.008	0.007	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0002	0.0003	0.0001	0.0001	0.0001	0.0001	0.0002	0.0003	0.0001	0.0001	0.0001	0.0001	0.0002	0.0003	0.0001	0.0001	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050
Silicon (Si)	mg/L	-	-	9	9	9	8	9	9	9	9	9	8	9	9	9	9	9	8	9	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.003	0.003	0.003	0.002	0.002	0.002	0.003	0.003	0.003	0.002	0.002	0.002	0.003	0.003	0.003	0.002	0.100	0.100	0.096	0.094	0.096	0.099
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.014	0.014	0.013	0.013	0.013	0.014

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-9 Water Quality Results From Mine Area 5,000 m Downstream of Clarification Pond Outlets (continued)

Ankaja River 5,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	40	40	42	39	43	45	40	40	42	39	43	45	40	40	42	39	43	33	29	29	30	29	32
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.05	0.18	0.15	0.15	0.16	0.15	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.5	1.5	1.5	1.6	1.6	1.6	1.5	1.5	1.5	1.6	1.6	1.6	1.5	1.5	1.5	1.6	1.4	1.3	1.3	1.3	1.3	1.3
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.5	2.4	2.5	2.4	2.5	2.6	2.5	2.4	2.5	2.4	2.5	2.6	2.5	2.4	2.5	2.4	2.5	3.2	3.0	3.0	3.0	3.0	3.1
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	7	8	7	8	8	7	7	8	7	8	8	7	7	8	7	8	7	6	6	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.9	0.8	0.8	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.5	2.5	2.6	2.5	2.7	2.8	2.5	2.5	2.6	2.5	2.7	2.8	2.5	2.5	2.6	2.5	2.7	1.3	1.2	1.2	1.2	1.2	1.2
Sulphate (SO ₄)	mg/L	-	-	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	2	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0013	0.0013	0.0012	0.0015	0.0003	0.0003	0.0013	0.0013	0.0012	0.0015	0.0003	0.0003	0.0013	0.0013	0.0012	0.0015	0.0003	0.0500	0.0448	0.0450	0.0453	0.0447	0.0484
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0005	0.0004	0.0002	0.0005	0.0002	0.0002	0.0005	0.0004	0.0002	0.0005	0.0002	0.0002	0.0005	0.0004	0.0002	0.0005	0.0002	0.0055	0.0051	0.0051	0.0051	0.0051	0.0053
Barium (Ba)	mg/L	0.7	-	0.013	0.022	0.021	0.012	0.022	0.013	0.013	0.022	0.021	0.012	0.022	0.013	0.013	0.022	0.021	0.013	0.022	0.013	0.025	0.033	0.032	0.031	0.033	0.024
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.006	0.006	0.006	0.006	0.006
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0006	0.0006	0.0005	0.0005	0.0005	0.0005	0.0006	0.0006	0.0005	0.0005	0.0005	0.0005	0.0006	0.0006	0.0005	0.0050	0.0045	0.0045	0.0045	0.0045	0.0048
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.027	0.023	0.007	0.029	0.008	0.008	0.027	0.023	0.007	0.029	0.008	0.008	0.027	0.023	0.008	0.029	0.008	0.006	0.026	0.022	0.023	0.027	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.004	0.004	0.005	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.005	0.005	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.3	1.3	1.3	1.2	1.4	1.4	1.3	1.3	1.3	1.2	1.4	1.4	1.3	1.3	1.3	1.2	1.4	1.1	1.0	1.0	1.0	1.0	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.050	0.045	0.045	0.045	0.044	0.048
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.07	
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0005	0.0005	0.0004	0.0005	
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0015	0.0013	0.0005	0.0015	0.0005	0.0005	0.0015	0.0013	0.0005	0.0015	0.0005	0.0005	0.0015	0.0013	0.0005	0.0015	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0004	0.0004	0.0002	0.0004	0.0001	0.0001	0.0004	0.0004	0.0002	0.0004	0.0001	0.0001	0.0004	0.0004	0.0002	0.0004	0.0001	0.0050	0.0047	0.0047	0.0047	0.0047	0.0048
Silicon (Si)	mg/L	-	-	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.100	0.090	0.090	0.091	0.089	0.097
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.014	0.013	0.013	0.013	0.013	0.013

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-10 Water Quality Results From Mine Area 6,500 m Downstream of Clarification Pond Outlets

Antsahalava River 6,500 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	29	28	29	28	33	33	29	28	29	28	33	33	29	28	29	29	33	45	39	38	39	39	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.15	0.14	0.15	0.15	0.17	0.18	0.15	0.14	0.15	0.15	0.17	0.18	0.15	0.14	0.15	0.15	0.17	0.05	0.04	0.04	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.0	2.9	3.0	3.0	3.2	3.2	3.0	2.9	3.0	3.0	3.2	3.2	3.0	3.0	3.0	3.0	3.2	2.6	2.5	2.5	2.5	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	6	6	6	6	7	7	6	6	6	6	7	7	6	6	6	6	7	8	7	7	7	7	8
Potassium (K)	mg/L	-	-	0.9	0.8	0.7	0.8	0.8	0.9	0.9	0.8	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.8	0.8	0.9	0.8	0.7	0.7	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	1.3	1.5	1.7	1.6	1.6	1.3	1.3	1.5	1.7	1.6	1.6	1.3	1.3	1.5	1.7	1.6	1.6	1.3	2.8	2.8	2.9	2.8	2.8	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0444	0.0421	0.0437	0.0429	0.0498	0.0500	0.0445	0.0422	0.0438	0.0431	0.0498	0.0500	0.0445	0.0423	0.0440	0.0433	0.0498	0.0003	0.0012	0.0014	0.0013	0.0014	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0052	0.0052	0.0052	0.0052	0.0054	0.0055	0.0052	0.0052	0.0052	0.0052	0.0054	0.0055	0.0052	0.0052	0.0052	0.0052	0.0054	0.0002	0.0006	0.0008	0.0007	0.0007	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.047	0.060	0.051	0.055	0.025	0.025	0.047	0.060	0.050	0.054	0.025	0.025	0.047	0.059	0.050	0.053	0.025	0.013	0.036	0.047	0.037	0.041	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.005	0.005	0.005	0.005	0.005	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0044	0.0042	0.0044	0.0043	0.0050	0.0050	0.0044	0.0042	0.0044	0.0043	0.0050	0.0050	0.0044	0.0042	0.0044	0.0043	0.0050	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.012	0.013	0.013	0.013	0.006	0.006	0.012	0.013	0.013	0.013	0.006	0.006	0.012	0.013	0.013	0.013	0.006	0.008	0.014	0.014	0.014	0.014	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.0	1.0	1.0	1.1	1.4	1.2	1.2	1.2	1.2	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.044	0.041	0.043	0.042	0.050	0.050	0.044	0.042	0.043	0.043	0.050	0.050	0.044	0.042	0.043	0.043	0.050	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0023	0.0030	0.0023	0.0026	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0049	0.0048	0.0048	0.0048	0.0050	0.0050	0.0049	0.0048	0.0048	0.0048	0.0050	0.0050	0.0049	0.0049	0.0049	0.0049	0.0050	0.0001	0.0006	0.0008	0.0006	0.0007	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	8	8	8	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.006	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.089	0.084	0.087	0.086	0.100	0.100	0.089	0.084	0.088	0.086	0.100	0.100	0.089	0.085	0.088	0.087	0.100	0.002	0.004	0.004	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.013	0.013	0.013	0.013	0.014	0.014	0.013	0.013	0.013	0.013	0.014	0.014	0.013	0.013	0.013	0.013	0.014	0.003	0.003	0.004	0.003	0.004	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-10 Water Quality Results From Mine Area 6,500 m Downstream of Clarification Pond Outlets (continued)

Antsahalava River 6,500 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	39	38	39	39	44	45	39	38	39	39	44	45	39	38	39	39	44	45	39	38	39	39	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	7	7	7	8	8	7	7	7	7	8	8	7	7	7	7	8	8	7	7	7	7	8
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	2.8	2.8	2.9	2.8	2.8	2.7	2.8	2.8	2.9	2.8	2.8	2.7	2.8	2.8	2.9	2.8	2.8	2.7	2.8	2.8	2.9	2.8	2.8	2.7
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0012	0.0014	0.0013	0.0014	0.0003	0.0003	0.0012	0.0014	0.0013	0.0014	0.0003	0.0003	0.0012	0.0014	0.0013	0.0014	0.0003	0.0003	0.0012	0.0014	0.0013	0.0014	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0006	0.0008	0.0007	0.0007	0.0002	0.0002	0.0006	0.0008	0.0007	0.0007	0.0002	0.0002	0.0006	0.0008	0.0007	0.0007	0.0002	0.0002	0.0006	0.0008	0.0007	0.0007	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.036	0.047	0.037	0.041	0.013	0.013	0.036	0.047	0.037	0.041	0.013	0.013	0.036	0.047	0.037	0.041	0.013	0.013	0.036	0.047	0.037	0.041	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.014	0.014	0.014	0.014	0.008	0.008	0.014	0.014	0.014	0.014	0.008	0.008	0.014	0.014	0.014	0.014	0.008	0.008	0.014	0.014	0.014	0.014	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.2	1.2	1.2	1.2	1.4	1.4	1.2	1.2	1.2	1.2	1.4	1.4	1.2	1.2	1.2	1.2	1.4	1.4	1.2	1.2	1.2	1.2	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0023	0.0030	0.0023	0.0026	0.0005	0.0005	0.0023	0.0030	0.0023	0.0026	0.0005	0.0005	0.0023	0.0030	0.0023	0.0026	0.0005	0.0005	0.0023	0.0030	0.0023	0.0026	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0006	0.0008	0.0006	0.0007	0.0001	0.0001	0.0006	0.0008	0.0006	0.0007	0.0001	0.0001	0.0006	0.0008	0.0006	0.0007	0.0001	0.0001	0.0006	0.0008	0.0006	0.0007	0.0001
Silicon (Si)	mg/L	-	-	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.006	0.005	0.005	0.004	0.005	0.005	0.006	0.005	0.005	0.004	0.005	0.005	0.006	0.005	0.005	0.004	0.005	0.005	0.006	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.004	0.003	0.004	0.002	0.003	0.003	0.004	0.003	0.004	0.002	0.003	0.003	0.004	0.003	0.004	0.002	0.003	0.003	0.004	0.003	0.004	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-10 Water Quality Results From Mine Area 6,500 m Downstream of Clarification Pond Outlets (continued)

Antsahalava River 6,500 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	39	38	39	39	44	45	39	38	39	39	44	45	39	38	39	39	44	33	29	28	29	28	33
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.18	0.15	0.14	0.15	0.15	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.4	1.4	1.4	1.4	1.4	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	3.2	3.0	2.9	3.0	3.0	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	7	7	7	7	8	8	7	7	7	7	8	8	7	7	7	7	8	7	6	6	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.9	0.8	0.8	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.8	2.9	2.8	2.8	2.7	2.8	2.8	2.9	2.8	2.8	2.7	2.8	2.8	2.9	2.8	2.8	2.7	1.3	1.5	1.7	1.6	1.6	1.3
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0012	0.0014	0.0013	0.0014	0.0003	0.0003	0.0012	0.0014	0.0013	0.0014	0.0003	0.0003	0.0012	0.0014	0.0013	0.0014	0.0003	0.0500	0.0445	0.0422	0.0438	0.0431	0.0498
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0006	0.0008	0.0007	0.0007	0.0002	0.0002	0.0006	0.0008	0.0007	0.0007	0.0002	0.0002	0.0006	0.0008	0.0007	0.0007	0.0002	0.0055	0.0052	0.0052	0.0052	0.0052	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.036	0.047	0.037	0.041	0.013	0.013	0.036	0.047	0.037	0.041	0.013	0.013	0.036	0.047	0.037	0.041	0.013	0.025	0.047	0.060	0.050	0.054	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.007	0.006	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0044	0.0042	0.0044	0.0043	0.0050
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.014	0.014	0.014	0.014	0.008	0.008	0.014	0.014	0.014	0.014	0.008	0.008	0.014	0.014	0.014	0.014	0.008	0.006	0.012	0.013	0.013	0.013	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.005	0.004	0.004	0.004	0.004	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.2	1.2	1.2	1.2	1.4	1.4	1.2	1.2	1.2	1.2	1.4	1.4	1.2	1.2	1.2	1.2	1.4	1.1	1.0	1.0	1.0	1.0	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.044	0.042	0.043	0.043	0.050
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0004	0.0004	0.0004	0.0004	0.0005	
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0023	0.0030	0.0023	0.0026	0.0005	0.0005	0.0023	0.0030	0.0023	0.0026	0.0005	0.0005	0.0023	0.0030	0.0023	0.0026	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0006	0.0008	0.0006	0.0007	0.0001	0.0001	0.0006	0.0008	0.0006	0.0007	0.0001	0.0001	0.0006	0.0008	0.0006	0.0007	0.0001	0.0050	0.0049	0.0048	0.0048	0.0048	0.0050
Silicon (Si)	mg/L	-	-	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.006	0.005	0.005	0.004	0.005	0.005	0.006	0.005	0.005	0.004	0.005	0.005	0.006	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.100	0.089	0.084	0.088	0.086	0.100
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.004	0.004	0.004	0.004	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.004	0.003	0.004	0.002	0.003	0.003	0.004	0.003	0.004	0.002	0.003	0.003	0.004	0.003	0.004	0.002	0.014	0.013	0.013	0.013	0.013	0.014

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-11 Water Quality Results From Mine Area 7,500 m Downstream of Clarification Pond Outlets

Antsahalava River 7,500 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	31	30	31	31	33	33	31	30	31	31	33	33	31	30	31	31	33	45	42	41	42	42	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.16	0.16	0.16	0.16	0.17	0.18	0.16	0.16	0.16	0.16	0.17	0.18	0.16	0.16	0.16	0.16	0.17	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.1	3.1	3.1	3.1	3.2	3.2	3.1	3.1	3.1	3.1	3.2	3.2	3.1	3.1	3.1	3.1	3.2	2.6	2.6	2.6	2.6	2.6	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	7	6	7	7	7	7	7	6	7	7	7	7	7	6	7	7	7	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.9	0.8	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.8	0.8	0.9	0.8	0.7	0.7	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	1.3	1.4	1.5	1.4	1.4	1.3	1.3	1.4	1.5	1.4	1.4	1.3	1.3	1.4	1.5	1.4	1.4	1.3	2.8	2.8	2.8	2.8	2.8	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0473	0.0461	0.0468	0.0465	0.0499	0.0500	0.0473	0.0461	0.0469	0.0466	0.0499	0.0500	0.0473	0.0462	0.0470	0.0467	0.0499	0.0003	0.0008	0.0008	0.0008	0.0008	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0053	0.0053	0.0053	0.0053	0.0054	0.0055	0.0054	0.0053	0.0053	0.0053	0.0054	0.0055	0.0054	0.0053	0.0053	0.0053	0.0054	0.0002	0.0004	0.0005	0.0004	0.0004	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.036	0.043	0.038	0.040	0.025	0.025	0.035	0.042	0.038	0.039	0.025	0.025	0.035	0.042	0.037	0.039	0.025	0.013	0.024	0.029	0.025	0.026	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.005	0.005	0.005	0.005	0.005	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0047	0.0046	0.0047	0.0046	0.0050	0.0050	0.0047	0.0046	0.0047	0.0047	0.0050	0.0050	0.0047	0.0046	0.0047	0.0047	0.0050	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.009	0.010	0.010	0.010	0.006	0.006	0.009	0.010	0.009	0.010	0.006	0.006	0.009	0.010	0.009	0.009	0.006	0.008	0.011	0.011	0.011	0.011	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.1	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.4	1.3	1.3	1.3	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.047	0.046	0.047	0.046	0.050	0.050	0.047	0.046	0.047	0.046	0.050	0.050	0.047	0.046	0.047	0.046	0.050	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0013	0.0017	0.0014	0.0015	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.008	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0049	0.0049	0.0049	0.0049	0.0050	0.0050	0.0049	0.0049	0.0049	0.0049	0.0050	0.0050	0.0049	0.0049	0.0049	0.0049	0.0050	0.0001	0.0003	0.0004	0.0003	0.0004	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	8	8	8	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.095	0.092	0.094	0.093	0.100	0.100	0.095	0.092	0.094	0.093	0.100	0.100	0.095	0.092	0.094	0.093	0.100	0.002	0.003	0.003	0.003	0.003	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.013	0.013	0.013	0.013	0.014	0.014	0.013	0.013	0.013	0.013	0.014	0.014	0.013	0.013	0.013	0.013	0.014	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-11 Water Quality Results From Mine Area 7,500 m Downstream of Clarification Pond Outlets (continued)

Sahaviara River 7,500 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	31	31	30	31	33	33	31	31	31	31	33	33	31	31	31	31	33	45	43	43	42	42	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.17	0.17	0.16	0.16	0.17	0.18	0.17	0.17	0.16	0.16	0.17	0.18	0.17	0.17	0.16	0.16	0.17	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.1	3.1	3.1	3.1	3.2	3.2	3.1	3.1	3.1	3.1	3.2	3.2	3.1	3.1	3.1	3.1	3.2	2.6	2.6	2.6	2.5	2.6	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.9	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.9	0.8	0.7	0.7	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	2.8	2.7	2.7	2.8	2.7	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0478	0.0475	0.0465	0.0470	0.0498	0.0500	0.0479	0.0476	0.0465	0.0470	0.0498	0.0500	0.0479	0.0476	0.0466	0.0471	0.0498	0.0003	0.0005	0.0005	0.0006	0.0005	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0053	0.0053	0.0053	0.0053	0.0054	0.0055	0.0053	0.0053	0.0053	0.0053	0.0054	0.0055	0.0053	0.0053	0.0053	0.0053	0.0054	0.0002	0.0003	0.0003	0.0004	0.0003	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.031	0.031	0.038	0.035	0.025	0.025	0.030	0.031	0.038	0.035	0.025	0.025	0.030	0.031	0.037	0.034	0.025	0.013	0.019	0.019	0.024	0.021	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.007	0.007	0.006	0.006	0.006	0.007	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0048	0.0048	0.0046	0.0047	0.0050	0.0050	0.0048	0.0048	0.0047	0.0047	0.0050	0.0050	0.0048	0.0048	0.0047	0.0047	0.0050	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.007	0.008	0.008	0.008	0.006	0.006	0.007	0.008	0.008	0.008	0.006	0.006	0.007	0.008	0.008	0.008	0.006	0.008	0.009	0.009	0.009	0.009	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005
Iron (Fe)	mg/L	-	-	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.4	1.3	1.3	1.3	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.048	0.047	0.046	0.047	0.050	0.050	0.048	0.047	0.046	0.047	0.050	0.050	0.048	0.047	0.046	0.047	0.050	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0009	0.0009	0.0013	0.0011	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.008	0.007	0.007	0.008	0.008	0.008	0.008	0.007	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0049	0.0049	0.0049	0.0049	0.0050	0.0050	0.0049	0.0049	0.0049	0.0049	0.0050	0.0050	0.0049	0.0049	0.0049	0.0049	0.0050	0.0001	0.0002	0.0002	0.0003	0.0002	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	9	9	8	9	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.096	0.095	0.093	0.094	0.100	0.100	0.096	0.095	0.093	0.094	0.100	0.100	0.096	0.095	0.093	0.094	0.100	0.002	0.002	0.002	0.002	0.002	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.013	0.013	0.013	0.013	0.014	0.014	0.013	0.013	0.013	0.013	0.014	0.014	0.013	0.013	0.013	0.013	0.014	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-11 Water Quality Results From Mine Area 7,500 m Downstream of Clarification Pond Outlets (continued)

Sahamarirana River 7,500 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	29	29	30	30	32	33	30	29	30	30	32	33	30	29	30	30	32	45	40	40	41	41	43
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.16	0.15	0.16	0.16	0.17	0.18	0.16	0.15	0.16	0.16	0.17	0.18	0.16	0.15	0.16	0.16	0.17	0.05	0.04	0.04	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.0	3.0	3.0	3.0	3.1	3.2	3.0	3.0	3.0	3.0	3.1	3.2	3.0	3.0	3.0	3.0	3.1	2.6	2.5	2.5	2.5	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	6	6	6	6	7	7	6	6	6	6	7	7	6	6	6	6	7	8	7	7	8	8	8
Potassium (K)	mg/L	-	-	0.9	0.8	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.8	0.8	0.9	0.8	0.7	0.7	0.7	0.7	0.7
Sodium (Na)	mg/L	-	-	1.3	1.4	1.4	1.3	1.3	1.2	1.3	1.4	1.4	1.3	1.3	1.2	1.3	1.4	1.4	1.3	1.3	1.2	2.8	2.7	2.7	2.6	2.6	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2	2	1	1	2	2	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0449	0.0444	0.0458	0.0455	0.0487	0.0500	0.0450	0.0445	0.0459	0.0456	0.0487	0.0500	0.0450	0.0447	0.0460	0.0457	0.0487	0.0003	0.0009	0.0009	0.0007	0.0007	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0051	0.0051	0.0051	0.0051	0.0053	0.0055	0.0051	0.0051	0.0051	0.0051	0.0053	0.0055	0.0051	0.0051	0.0051	0.0051	0.0053	0.0002	0.0004	0.0004	0.0003	0.0003	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.035	0.037	0.030	0.031	0.024	0.025	0.035	0.037	0.029	0.031	0.024	0.025	0.035	0.036	0.029	0.031	0.024	0.013	0.024	0.025	0.018	0.019	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006	0.006	0.007	0.006	0.006	0.006	0.006	0.006	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0045	0.0044	0.0046	0.0046	0.0049	0.0050	0.0045	0.0045	0.0046	0.0046	0.0049	0.0050	0.0045	0.0045	0.0046	0.0046	0.0049	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.011	0.011	0.008	0.007	0.006	0.006	0.011	0.011	0.008	0.007	0.006	0.006	0.011	0.011	0.008	0.007	0.006	0.008	0.012	0.012	0.009	0.008	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.002	0.001	0.001	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.0	1.1	1.0	1.1	1.1	1.0	1.0	1.1	1.0	1.1	1.4	1.3	1.3	1.3	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.045	0.044	0.046	0.045	0.049	0.050	0.045	0.044	0.046	0.045	0.049	0.050	0.045	0.044	0.046	0.046	0.049	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.06	0.06	0.07	0.07	0.07	0.07	0.06	0.06	0.07	0.07	0.07	0.07	0.06	0.06	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0004	0.0005	0.0005	0.0005	0.0005	0.0005	0.0004	0.0005	0.0005	0.0005	0.0005	0.0005	0.0004	0.0005	0.0005	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0014	0.0015	0.0009	0.0009	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0047	0.0047	0.0047	0.0047	0.0049	0.0050	0.0047	0.0047	0.0047	0.0047	0.0049	0.0050	0.0047	0.0047	0.0047	0.0047	0.0049	0.0001	0.0004	0.0004	0.0002	0.0002	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	8	8	8	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.090	0.089	0.092	0.091	0.097	0.100	0.090	0.089	0.092	0.091	0.097	0.100	0.090	0.089	0.092	0.091	0.097	0.002	0.003	0.003	0.003	0.003	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.013	0.013	0.013	0.013	0.013	0.014	0.013	0.013	0.013	0.013	0.013	0.014	0.013	0.013	0.013	0.013	0.013	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-11 Water Quality Results From Mine Area 7,500 m Downstream of Clarification Pond Outlets (continued)

Sakalava River 7,500 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	33	32	31	32	33	33	33	32	31	32	33	33	33	32	31	32	33	45	45	44	42	44	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.18	0.17	0.17	0.17	0.17	0.18	0.18	0.17	0.17	0.17	0.17	0.18	0.18	0.17	0.17	0.17	0.17	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.2	3.1	3.1	3.1	3.2	3.2	3.2	3.1	3.1	3.1	3.2	3.2	3.2	3.1	3.1	3.2	3.2	2.6	2.6	2.6	2.6	2.6	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.9	0.9	0.9	0.8	0.9	0.9	0.9	0.9	0.9	0.8	0.9	0.9	0.9	0.9	0.9	0.8	0.9	0.9	0.8	0.8	0.7	0.7	0.8	
Sodium (Na)	mg/L	-	-	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	2.8	2.8	2.7	2.7	2.7	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0500	0.0482	0.0477	0.0482	0.0498	0.0500	0.0500	0.0485	0.0477	0.0486	0.0498	0.0500	0.0500	0.0488	0.0477	0.0490	0.0498	0.0003	0.0003	0.0008	0.0008	0.0007	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0002	0.0002	0.0002	0.0003	0.0002	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.025	0.028	0.030	0.028	0.025	0.025	0.025	0.027	0.030	0.026	0.025	0.025	0.025	0.026	0.030	0.025	0.025	0.013	0.013	0.013	0.018	0.013	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0050	0.0048	0.0048	0.0048	0.0050	0.0050	0.0050	0.0048	0.0048	0.0049	0.0050	0.0050	0.0050	0.0049	0.0048	0.0049	0.0050	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.006	0.014	0.018	0.013	0.006	0.006	0.006	0.012	0.018	0.009	0.006	0.006	0.006	0.009	0.018	0.007	0.006	0.008	0.008	0.008	0.020	0.008	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Iron (Fe)	mg/L	-	-	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.4	1.4	1.4	1.3	1.4	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.050	0.048	0.048	0.048	0.050	0.050	0.050	0.048	0.048	0.049	0.050	0.050	0.050	0.049	0.048	0.049	0.050	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0005	0.0005	0.0011	0.0005	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0001	0.0001	0.0001	0.0003	0.0001	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	9	9	9	9	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.100	0.096	0.095	0.096	0.100	0.100	0.100	0.097	0.095	0.097	0.100	0.100	0.100	0.098	0.095	0.098	0.100	0.002	0.002	0.003	0.003	0.003	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.003	0.003	0.002	0.003	0.002	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-11 Water Quality Results From Mine Area 7,500 m Downstream of Clarification Pond Outlets (continued)

Sakalava River 7,500 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	33	32	31	32	33	33	33	32	31	32	33	33	33	32	31	32	33	45	45	44	42	44	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.18	0.17	0.17	0.17	0.17	0.18	0.18	0.17	0.17	0.17	0.17	0.18	0.18	0.17	0.17	0.17	0.17	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.2	3.1	3.1	3.1	3.2	3.2	3.2	3.1	3.1	3.1	3.2	3.2	3.2	3.1	3.1	3.2	3.2	2.6	2.6	2.6	2.6	2.6	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.9	0.9	0.9	0.8	0.9	0.9	0.9	0.9	0.9	0.8	0.9	0.9	0.9	0.9	0.9	0.8	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	2.8	2.8	2.7	2.7	2.7	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0500	0.0482	0.0477	0.0482	0.0498	0.0500	0.0500	0.0485	0.0477	0.0486	0.0498	0.0500	0.0500	0.0488	0.0477	0.0490	0.0498	0.0003	0.0003	0.0008	0.0008	0.0007	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054	0.0002	0.0002	0.0002	0.0003	0.0002	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.025	0.028	0.030	0.028	0.025	0.025	0.025	0.027	0.030	0.026	0.025	0.025	0.025	0.026	0.030	0.025	0.025	0.013	0.013	0.013	0.018	0.013	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0050	0.0048	0.0048	0.0048	0.0050	0.0050	0.0050	0.0048	0.0048	0.0049	0.0050	0.0050	0.0050	0.0049	0.0048	0.0049	0.0050	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.006	0.014	0.018	0.013	0.006	0.006	0.006	0.012	0.018	0.009	0.006	0.006	0.006	0.009	0.018	0.007	0.006	0.008	0.008	0.008	0.020	0.008	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Iron (Fe)	mg/L	-	-	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.4	1.4	1.4	1.3	1.4	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.050	0.048	0.048	0.048	0.050	0.050	0.050	0.048	0.048	0.049	0.050	0.050	0.050	0.049	0.048	0.049	0.050	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0005	0.0005	0.0011	0.0005	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050	0.0001	0.0001	0.0001	0.0003	0.0001	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	9	9	9	9	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.100	0.096	0.095	0.096	0.100	0.100	0.100	0.097	0.095	0.097	0.100	0.100	0.100	0.098	0.095	0.098	0.100	0.002	0.002	0.003	0.003	0.003	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.003	0.003	0.002	0.003	0.002	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-11 Water Quality Results From Mine Area 7,500 m Downstream of Clarification Pond Outlets (continued)

Antsahalava River 7,500 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	42	41	42	42	44	45	42	41	42	42	44	45	42	41	42	42	44	45	42	41	42	42	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	2.8	2.8	2.8	2.8	2.8	2.7	2.8	2.8	2.8	2.8	2.8	2.7	2.8	2.8	2.8	2.8	2.8	2.7	2.8	2.8	2.8	2.8	2.8	2.7
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0008	0.0008	0.0008	0.0008	0.0003	0.0003	0.0008	0.0008	0.0008	0.0008	0.0003	0.0003	0.0008	0.0008	0.0008	0.0008	0.0003	0.0003	0.0008	0.0008	0.0008	0.0008	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0004	0.0005	0.0004	0.0004	0.0002	0.0002	0.0004	0.0005	0.0004	0.0004	0.0002	0.0002	0.0004	0.0005	0.0004	0.0004	0.0002	0.0002	0.0004	0.0005	0.0004	0.0004	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.024	0.029	0.025	0.026	0.013	0.013	0.024	0.029	0.025	0.026	0.013	0.013	0.024	0.029	0.025	0.026	0.013	0.013	0.024	0.029	0.025	0.026	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.011	0.011	0.011	0.011	0.008	0.008	0.011	0.011	0.011	0.011	0.008	0.008	0.011	0.011	0.011	0.011	0.008	0.008	0.011	0.011	0.011	0.011	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0013	0.0017	0.0014	0.0015	0.0005	0.0005	0.0013	0.0017	0.0014	0.0015	0.0005	0.0005	0.0013	0.0017	0.0014	0.0015	0.0005	0.0005	0.0013	0.0017	0.0014	0.0015	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0003	0.0004	0.0003	0.0004	0.0001	0.0001	0.0003	0.0004	0.0003	0.0004	0.0001	0.0001	0.0003	0.0004	0.0003	0.0004	0.0001	0.0001	0.0003	0.0004	0.0003	0.0004	0.0001
Silicon (Si)	mg/L	-	-	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-11 Water Quality Results From Mine Area 7,500 m Downstream of Clarification Pond Outlets (continued)

Sahaviara River 7,500 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	43	43	42	42	44	45	43	43	42	42	44	45	43	43	42	42	44	45	43	43	42	42	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.6	2.5	2.6	2.6	2.6	2.6	2.6	2.5	2.6	2.6	2.6	2.6	2.6	2.5	2.6	2.6	2.6	2.6	2.5	2.6	2.6	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7
Sulphate (SO ₄)	mg/L	-	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0005	0.0005	0.0006	0.0005	0.0003	0.0003	0.0005	0.0005	0.0006	0.0005	0.0003	0.0003	0.0005	0.0005	0.0006	0.0005	0.0003	0.0003	0.0005	0.0005	0.0006	0.0005	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0003	0.0003	0.0004	0.0003	0.0002	0.0002	0.0003	0.0003	0.0004	0.0003	0.0002	0.0002	0.0003	0.0003	0.0004	0.0003	0.0002	0.0002	0.0003	0.0003	0.0004	0.0003	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.019	0.019	0.024	0.021	0.013	0.013	0.019	0.019	0.024	0.021	0.013	0.013	0.019	0.019	0.024	0.021	0.013	0.013	0.019	0.019	0.024	0.021	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.009	0.009	0.009	0.009	0.008	0.008	0.009	0.009	0.009	0.009	0.008	0.008	0.009	0.009	0.009	0.009	0.008	0.008	0.009	0.009	0.009	0.009	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005
Iron (Fe)	mg/L	-	-	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0009	0.0009	0.0013	0.0011	0.0005	0.0005	0.0009	0.0009	0.0013	0.0011	0.0005	0.0005	0.0009	0.0009	0.0013	0.0011	0.0005	0.0005	0.0009	0.0009	0.0013	0.0011	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0002	0.0002	0.0003	0.0002	0.0001	0.0001	0.0002	0.0002	0.0003	0.0002	0.0001	0.0001	0.0002	0.0002	0.0003	0.0002	0.0001	0.0001	0.0002	0.0002	0.0003	0.0002	0.0001
Silicon (Si)	mg/L	-	-	9	9	9	8	9	9	9	9	9	8	9	9	9	9	9	8	9	9	9	9	9	8	9	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-11 Water Quality Results From Mine Area 7,500 m Downstream of Clarification Pond Outlets (continued)

Sahamarirana River 7,500 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	40	40	41	41	43	45	40	40	41	41	43	45	40	40	41	41	43	45	40	40	41	41	43
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
Chloride (Cl)	mg/L	-	-	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	8	7	7	8	8	8	8	7	7	8	8	8	8	7	7	8	8	8	8	7	7	8	8	
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	
Sodium (Na)	mg/L	-	-	2.8	2.7	2.7	2.6	2.6	2.7	2.8	2.7	2.7	2.6	2.6	2.7	2.8	2.7	2.7	2.6	2.6	2.7	2.8	2.7	2.7	2.6	2.6	
Sulphate (SO ₄)	mg/L	-	-	1	2	2	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1	1	2	2	1	1	
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0009	0.0009	0.0007	0.0007	0.0003	0.0003	0.0009	0.0009	0.0007	0.0007	0.0003	0.0003	0.0009	0.0009	0.0007	0.0007	0.0003	0.0003	0.0009	0.0009	0.0007	0.0007	
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0004	0.0004	0.0003	0.0003	0.0002	0.0002	0.0004	0.0004	0.0003	0.0003	0.0002	0.0002	0.0004	0.0004	0.0003	0.0003	0.0002	0.0002	0.0004	0.0004	0.0003	0.0003	
Barium (Ba)	mg/L	0.7	-	0.013	0.024	0.025	0.018	0.019	0.013	0.013	0.024	0.025	0.018	0.019	0.013	0.013	0.024	0.025	0.018	0.019	0.013	0.013	0.024	0.025	0.018	0.019	
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.012	0.012	0.009	0.008	0.008	0.008	0.012	0.012	0.009	0.008	0.008	0.008	0.012	0.012	0.009	0.008	0.008	0.008	0.012	0.012	0.009	0.008	
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.002	0.002	0.002	0.002	0.001	0.001	0.002	0.002	0.002	0.002	0.001	0.001	0.002	0.002	0.002	0.002	0.001	0.001	0.002	0.002	
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.005	
Iron (Fe)	mg/L	-	-	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.4	
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0014	0.0015	0.0009	0.0009	0.0005	0.0005	0.0014	0.0015	0.0009	0.0009	0.0005	0.0005	0.0014	0.0015	0.0009	0.0009	0.0005	0.0005	0.0014	0.0015	0.0009	0.0009	
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.008	
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0004	0.0004	0.0002	0.0002	0.0001	0.0001	0.0004	0.0004	0.0002	0.0002	0.0001	0.0001	0.0004	0.0004	0.0002	0.0002	0.0001	0.0001	0.0004	0.0004	0.0002	0.0001	
Silicon (Si)	mg/L	-	-	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	9	
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.004	
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.002	
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.002	

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-11 Water Quality Results From Mine Area 7,500 m Downstream of Clarification Pond Outlets (continued)

Sakalava River 7,500 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	44	42	44	44	45	45	44	42	44	44	45	45	44	42	44	44	45	45	44	42	44	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	2.8	2.8	2.7	2.7	2.7	2.7	2.8	2.8	2.7	2.7	2.7	2.7	2.8	2.8	2.7	2.7	2.7	2.7	2.8	2.8	2.7	2.7	2.7	2.7
Sulphate (SO ₄)	mg/L	-	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0008	0.0008	0.0007	0.0003	0.0003	0.0003	0.0008	0.0008	0.0007	0.0003	0.0003	0.0003	0.0008	0.0008	0.0007	0.0003	0.0003	0.0003	0.0008	0.0008	0.0007	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0002	0.0003	0.0002	0.0002	0.0002	0.0002	0.0002	0.0003	0.0002	0.0002	0.0002	0.0002	0.0002	0.0003	0.0002	0.0002	0.0002	0.0002	0.0003	0.0002	0.0002	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.013	0.018	0.013	0.013	0.013	0.013	0.013	0.018	0.013	0.013	0.013	0.013	0.013	0.018	0.013	0.013	0.013	0.013	0.018	0.013	0.013	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.008	0.020	0.008	0.008	0.008	0.008	0.008	0.020	0.008	0.008	0.008	0.008	0.008	0.020	0.008	0.008	0.008	0.008	0.008	0.020	0.008	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.4	1.3	1.4	1.4	1.4	1.4	1.4	1.3	1.4	1.4	1.4	1.4	1.4	1.3	1.4	1.4	1.4	1.4	1.4	1.3	1.4	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0005	0.0011	0.0005	0.0005	0.0005	0.0005	0.0005	0.0011	0.0005	0.0005	0.0005	0.0005	0.0005	0.0011	0.0005	0.0005	0.0005	0.0005	0.0005	0.0011	0.0005	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.008	0.007	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0001	0.0003	0.0001	0.0001	0.0001	0.0001	0.0001	0.0003	0.0001	0.0001	0.0001	0.0001	0.0001	0.0003	0.0001	0.0001	0.0001	0.0001	0.0003	0.0001	0.0001	0.0001
Silicon (Si)	mg/L	-	-	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.003	0.003	0.003	0.002	0.002	0.002	0.003	0.003	0.003	0.002	0.002	0.002	0.003	0.003	0.003	0.002	0.002	0.002	0.003	0.003	0.003	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-11 Water Quality Results From Mine Area 7,500 m Downstream of Clarification Pond Outlets (continued)

Ankaja River 7,500 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	40	40	42	40	43	45	40	40	42	40	43	45	40	40	42	40	43	45	40	40	42	40	43
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6	1.6	1.5	1.6	
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
Chloride (Cl)	mg/L	-	-	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.6	
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	
Sodium (Na)	mg/L	-	-	2.8	2.6	2.6	2.6	2.5	2.7	2.8	2.6	2.6	2.6	2.5	2.7	2.8	2.6	2.6	2.6	2.5	2.7	2.8	2.6	2.6	2.6	2.5	
Sulphate (SO ₄)	mg/L	-	-	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0012	0.0012	0.0011	0.0013	0.0003	0.0003	0.0012	0.0012	0.0011	0.0013	0.0003	0.0003	0.0012	0.0012	0.0011	0.0013	0.0003	0.0003	0.0012	0.0012	0.0011	0.0013	
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0004	0.0004	0.0002	0.0005	0.0002	0.0002	0.0004	0.0004	0.0002	0.0005	0.0002	0.0002	0.0004	0.0004	0.0002	0.0005	0.0002	0.0002	0.0004	0.0004	0.0002	0.0005	
Barium (Ba)	mg/L	0.7	-	0.013	0.021	0.020	0.013	0.021	0.013	0.013	0.021	0.020	0.013	0.021	0.013	0.013	0.021	0.020	0.013	0.021	0.013	0.013	0.021	0.020	0.013	0.021	
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0006	0.0005	0.0005	0.0005	0.0005	0.0005	0.0006	0.0005	0.0005	0.0005	0.0005	0.0005	0.0006	0.0005	0.0005	0.0005	0.0005	0.0006	0.0005	
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.025	0.021	0.007	0.026	0.008	0.008	0.025	0.021	0.007	0.026	0.008	0.008	0.025	0.021	0.007	0.026	0.008	0.008	0.025	0.021	0.007	0.026	
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.005	0.004	0.005	0.005	0.004	0.004	0.005	0.004	0.005	0.005	0.004	0.004	0.005	0.004	0.005	0.005	0.004	0.004	0.005	0.004	
Iron (Fe)	mg/L	-	-	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.4	
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0014	0.0012	0.0005	0.0014	0.0005	0.0005	0.0014	0.0012	0.0005	0.0014	0.0005	0.0005	0.0014	0.0012	0.0005	0.0014	0.0005	0.0005	0.0014	0.0012	0.0005	0.0014	
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.008	
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0004	0.0003	0.0002	0.0004	0.0001	0.0001	0.0004	0.0003	0.0002	0.0004	0.0001	0.0001	0.0004	0.0003	0.0002	0.0004	0.0001	0.0001	0.0004	0.0003	0.0002	0.0004	
Silicon (Si)	mg/L	-	-	9	8	8	9	8	9	9	8	8	9	8	9	9	8	8	9	8	9	9	8	8	9	8	
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.004	
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.002	
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-11 Water Quality Results From Mine Area 7,500 m Downstream of Clarification Pond Outlets (continued)

Antsahalava River 7,500 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	42	41	42	42	44	45	42	41	42	42	44	45	42	41	42	42	44	33	31	30	31	31	33
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.18	0.16	0.16	0.16	0.16	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.4	1.4	1.4	1.4	1.4	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	3.2	3.1	3.1	3.1	3.1	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7	7	6	7	7	7
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.9	0.8	0.8	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.8	2.8	2.8	2.8	2.7	2.8	2.8	2.8	2.8	2.8	2.7	2.8	2.8	2.8	2.8	2.8	2.7	1.3	1.4	1.5	1.4	1.4	1.3
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0008	0.0008	0.0008	0.0008	0.0003	0.0003	0.0008	0.0008	0.0008	0.0008	0.0003	0.0003	0.0008	0.0008	0.0008	0.0008	0.0003	0.0500	0.0473	0.0461	0.0469	0.0466	0.0499
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0004	0.0005	0.0004	0.0004	0.0002	0.0002	0.0004	0.0005	0.0004	0.0004	0.0002	0.0002	0.0004	0.0005	0.0004	0.0004	0.0002	0.0055	0.0054	0.0053	0.0053	0.0053	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.024	0.029	0.025	0.026	0.013	0.013	0.024	0.029	0.025	0.026	0.013	0.013	0.024	0.029	0.025	0.026	0.013	0.025	0.035	0.042	0.038	0.039	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.007	0.007	0.007	0.007	0.007	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0047	0.0046	0.0047	0.0047	0.0050
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.011	0.011	0.011	0.011	0.008	0.008	0.011	0.011	0.011	0.011	0.008	0.008	0.011	0.011	0.011	0.011	0.008	0.006	0.009	0.010	0.009	0.010	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Iron (Fe)	mg/L	-	-	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.1	1.1	1.1	1.1	1.1	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.047	0.046	0.047	0.046	0.050
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0013	0.0017	0.0014	0.0015	0.0005	0.0005	0.0013	0.0017	0.0014	0.0015	0.0005	0.0005	0.0013	0.0017	0.0014	0.0015	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0003	0.0004	0.0003	0.0004	0.0001	0.0001	0.0003	0.0004	0.0003	0.0004	0.0001	0.0001	0.0003	0.0004	0.0003	0.0004	0.0001	0.0050	0.0049	0.0049	0.0049	0.0049	0.0050
Silicon (Si)	mg/L	-	-	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.100	0.095	0.092	0.094	0.093	0.100
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.014	0.013	0.013	0.013	0.013	0.014

- Notes
- 1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.
- 2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.
- 3

Based on the un-ionized portion of ammonia.
- 4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.
- 5

Based on long-term exposure.
- 6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.
- 7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.
- 8

Based on an alkalinity value of less than 60 mg/L.
- 9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).
- 10

Based on the dissolved form of this metal.
- 11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.
- 12

Based on a dissolved saturation of at least 80%.
- 13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.
- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-11 Water Quality Results From Mine Area 7,500 m Downstream of Clarification Pond Outlets (continued)

Sahaviara River 7,500 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	43	43	42	42	44	45	43	43	42	42	44	45	43	43	42	42	44	33	31	31	31	31	33
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.18	0.17	0.17	0.16	0.16	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.4	1.4	1.4	1.4	1.4	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.6	2.5	2.6	2.6	2.6	2.6	2.6	2.5	2.6	2.6	2.6	2.6	2.6	2.5	2.6	2.6	3.2	3.1	3.1	3.1	3.1	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7	7	7	7	7	7
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.9	0.9	0.8	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	2.8	2.7	2.7	1.3	1.3	1.3	1.4	1.4	1.3
Sulphate (SO ₄)	mg/L	-	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0005	0.0005	0.0006	0.0005	0.0003	0.0003	0.0005	0.0005	0.0006	0.0005	0.0003	0.0003	0.0005	0.0005	0.0006	0.0006	0.0003	0.0500	0.0479	0.0476	0.0465	0.0470	0.0498
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0003	0.0003	0.0004	0.0003	0.0002	0.0002	0.0003	0.0003	0.0004	0.0003	0.0002	0.0002	0.0003	0.0003	0.0004	0.0003	0.0002	0.0055	0.0053	0.0053	0.0053	0.0053	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.019	0.019	0.024	0.021	0.013	0.013	0.019	0.019	0.024	0.021	0.013	0.013	0.019	0.019	0.024	0.022	0.013	0.025	0.030	0.031	0.038	0.034	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.007	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0048	0.0048	0.0047	0.0047	0.0050
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.009	0.009	0.009	0.009	0.008	0.008	0.009	0.009	0.009	0.009	0.008	0.008	0.009	0.009	0.009	0.009	0.008	0.006	0.007	0.008	0.008	0.008	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Iron (Fe)	mg/L	-	-	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.1	1.1	1.1	1.1	1.1	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.048	0.047	0.046	0.047	0.050
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0009	0.0009	0.0013	0.0011	0.0005	0.0005	0.0009	0.0009	0.0013	0.0011	0.0005	0.0005	0.0009	0.0009	0.0013	0.0011	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.008	0.008	0.007	0.008	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0002	0.0002	0.0003	0.0002	0.0001	0.0001	0.0002	0.0002	0.0003	0.0002	0.0001	0.0001	0.0002	0.0002	0.0003	0.0002	0.0001	0.0050	0.0049	0.0049	0.0049	0.0049	0.0050
Silicon (Si)	mg/L	-	-	9	9	9	8	9	9	9	9	9	8	9	9	9	9	9	8	9	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.100	0.096	0.095	0.093	0.094	0.100
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.014	0.013	0.013	0.013	0.013	0.014

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-11 Water Quality Results From Mine Area 7,500 m Downstream of Clarification Pond Outlets (continued)

Sahamarirana River 7,500 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	40	40	41	41	43	45	40	40	41	41	43	45	40	40	41	41	43	33	30	29	30	30	32
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.18	0.16	0.15	0.16	0.16	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.4	1.3	1.3	1.3	1.3	1.3
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	3.2	3.0	3.0	3.0	3.0	3.1
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	8	7	7	8	8	8	8	7	7	8	8	8	8	7	7	8	8	8	7	6	6	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.9	0.8	0.8	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.7	2.7	2.6	2.6	2.7	2.8	2.7	2.7	2.6	2.6	2.7	2.8	2.7	2.7	2.6	2.6	2.7	1.3	1.4	1.4	1.3	1.3	1.2
Sulphate (SO ₄)	mg/L	-	-	1	2	2	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1	2	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0009	0.0009	0.0007	0.0007	0.0003	0.0003	0.0009	0.0009	0.0007	0.0007	0.0003	0.0003	0.0009	0.0009	0.0007	0.0007	0.0003	0.0500	0.0450	0.0445	0.0459	0.0456	0.0487
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0004	0.0004	0.0003	0.0003	0.0002	0.0002	0.0004	0.0004	0.0003	0.0003	0.0002	0.0002	0.0004	0.0004	0.0003	0.0003	0.0002	0.0055	0.0051	0.0051	0.0051	0.0051	0.0053
Barium (Ba)	mg/L	0.7	-	0.013	0.024	0.025	0.018	0.019	0.013	0.013	0.024	0.025	0.018	0.019	0.013	0.013	0.024	0.025	0.018	0.019	0.013	0.025	0.035	0.037	0.029	0.031	0.024
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.006	0.006	0.006	0.006	0.006
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0045	0.0045	0.0046	0.0046	0.0049
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.012	0.012	0.009	0.008	0.008	0.008	0.012	0.012	0.009	0.008	0.008	0.008	0.012	0.012	0.009	0.008	0.008	0.006	0.011	0.011	0.008	0.007	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.001	0.001	0.002	0.002	0.002	0.002	0.001	0.001	0.002	0.002	0.002	0.002	0.001	0.001	0.002	0.002	0.002	0.005	0.004	0.004	0.005	0.005	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.005	0.004	0.005	0.005	0.005
Iron (Fe)	mg/L	-	-	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.1	1.0	1.0	1.1	1.0	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.045	0.044	0.046	0.045	0.049
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.07	0.07	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0004	0.0005	0.0005	0.0005	
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0014	0.0015	0.0009	0.0009	0.0005	0.0005	0.0014	0.0015	0.0009	0.0009	0.0005	0.0005	0.0014	0.0015	0.0009	0.0009	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0004	0.0004	0.0002	0.0002	0.0001	0.0001	0.0004	0.0004	0.0002	0.0002	0.0001	0.0001	0.0004	0.0004	0.0002	0.0002	0.0001	0.0050	0.0047	0.0047	0.0047	0.0047	0.0049
Silicon (Si)	mg/L	-	-	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.100	0.090	0.089	0.092	0.091	0.097
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.004	0.005	0.005	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.014	0.013	0.013	0.013	0.013	0.013

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-11 Water Quality Results From Mine Area 7,500 m Downstream of Clarification Pond Outlets (continued)

Sakalava River 7,500 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	45	44	42	44	44	45	45	44	42	44	44	45	45	44	42	44	44	33	33	32	31	32	33
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.18	0.18	0.17	0.17	0.17	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.4	1.4	1.4	1.4	1.4	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	3.2	3.2	3.1	3.1	3.1	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7	7	7	7	7	7
Potassium (K)	mg/L	-	-	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7	0.7	0.8	0.9	0.9	0.9	0.8	0.9	0.9
Sodium (Na)	mg/L	-	-	2.8	2.8	2.7	2.7	2.7	2.7	2.8	2.8	2.7	2.7	2.7	2.7	2.8	2.8	2.7	2.7	2.7	2.7	1.3	1.3	1.3	1.3	1.3	1.3
Sulphate (SO ₄)	mg/L	-	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0003	0.0008	0.0008	0.0007	0.0003	0.0003	0.0003	0.0008	0.0008	0.0007	0.0003	0.0003	0.0003	0.0008	0.0008	0.0007	0.0003	0.0500	0.0500	0.0485	0.0477	0.0487	0.0498
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0002	0.0002	0.0003	0.0002	0.0002	0.0002	0.0002	0.0002	0.0003	0.0002	0.0002	0.0002	0.0002	0.0002	0.0003	0.0002	0.0002	0.0055	0.0055	0.0053	0.0053	0.0053	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.013	0.013	0.018	0.013	0.013	0.013	0.013	0.013	0.018	0.013	0.013	0.013	0.013	0.013	0.018	0.013	0.013	0.025	0.025	0.027	0.030	0.026	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.007	0.007	0.007	0.007	0.007	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0050	0.0048	0.0048	0.0049	0.0050
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.008	0.008	0.020	0.008	0.008	0.008	0.008	0.008	0.020	0.008	0.008	0.008	0.008	0.008	0.020	0.008	0.008	0.006	0.006	0.012	0.018	0.009	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Iron (Fe)	mg/L	-	-	1.4	1.4	1.4	1.3	1.4	1.4	1.4	1.4	1.4	1.3	1.4	1.4	1.4	1.4	1.4	1.3	1.4	1.4	1.1	1.1	1.1	1.1	1.1	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.050	0.048	0.048	0.049	0.050
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0005	0.0005	0.0011	0.0005	0.0005	0.0005	0.0005	0.0005	0.0011	0.0005	0.0005	0.0005	0.0005	0.0005	0.0011	0.0005	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.008	0.007	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.008	0.008	0.008	0.008	0.007	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0001	0.0001	0.0003	0.0001	0.0001	0.0001	0.0001	0.0001	0.0003	0.0001	0.0001	0.0001	0.0001	0.0001	0.0003	0.0001	0.0001	0.0050	0.0050	0.0049	0.0049	0.0049	0.0050
Silicon (Si)	mg/L	-	-	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.005	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.002	0.003	0.003	0.003	0.002	0.002	0.002	0.003	0.003	0.003	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.100	0.100	0.097	0.095	0.097	0.100
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.003	0.002	0.002	0.014	0.014	0.013	0.013	0.013	0.014

- Notes
- 1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.
- 2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.
- 3

Based on the un-ionized portion of ammonia.
- 4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.
- 5

Based on long-term exposure.
- 6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.
- 7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.
- 8

Based on an alkalinity value of less than 60 mg/L.
- 9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).
- 10

Based on the dissolved form of this metal.
- 11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.
- 12

Based on a dissolved saturation of at least 80%.
- 13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.
- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-11 Water Quality Results From Mine Area 7,500 m Downstream of Clarification Pond Outlets (continued)

Ankaja River 7,500 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	40	40	42	40	43	45	40	40	42	40	43	45	40	40	42	40	43	33	30	30	30	30	32
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.18	0.16	0.16	0.16	0.16	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.4	1.3	1.3	1.3	1.3	1.3
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	3.2	3.0	3.0	3.0	3.0	3.1
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7	6	6	6	6	7
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.9	0.8	0.8	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.6	2.6	2.6	2.5	2.7	2.8	2.6	2.6	2.6	2.5	2.7	2.8	2.6	2.6	2.6	2.5	2.7	1.3	1.2	1.2	1.2	1.2	1.2
Sulphate (SO ₄)	mg/L	-	-	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1	2	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0012	0.0012	0.0011	0.0013	0.0003	0.0003	0.0012	0.0012	0.0011	0.0013	0.0003	0.0003	0.0012	0.0012	0.0011	0.0013	0.0003	0.0500	0.0454	0.0456	0.0458	0.0453	0.0486
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0004	0.0004	0.0002	0.0005	0.0002	0.0002	0.0004	0.0004	0.0002	0.0005	0.0002	0.0002	0.0004	0.0004	0.0002	0.0005	0.0002	0.0055	0.0052	0.0051	0.0052	0.0051	0.0053
Barium (Ba)	mg/L	0.7	-	0.013	0.021	0.020	0.013	0.021	0.013	0.013	0.021	0.020	0.013	0.021	0.013	0.013	0.021	0.020	0.013	0.021	0.013	0.025	0.032	0.031	0.030	0.032	0.024
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.006	0.006	0.006	0.006	0.006
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0006	0.0005	0.0005	0.0005	0.0005	0.0005	0.0006	0.0005	0.0005	0.0005	0.0005	0.0005	0.0006	0.0005	0.0050	0.0045	0.0046	0.0046	0.0045	0.0049
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.025	0.021	0.007	0.026	0.008	0.008	0.025	0.021	0.007	0.026	0.008	0.008	0.025	0.021	0.008	0.026	0.008	0.006	0.024	0.020	0.021	0.025	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.005	0.004	0.005	0.005	0.004	0.004	0.005	0.004	0.005	0.005	0.004	0.004	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Iron (Fe)	mg/L	-	-	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.1	1.0	1.0	1.1	1.0	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.045	0.045	0.046	0.045	0.049
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0014	0.0012	0.0005	0.0014	0.0005	0.0005	0.0014	0.0012	0.0005	0.0014	0.0005	0.0005	0.0014	0.0012	0.0005	0.0014	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0004	0.0003	0.0002	0.0004	0.0001	0.0001	0.0004	0.0003	0.0002	0.0004	0.0001	0.0001	0.0004	0.0003	0.0002	0.0004	0.0001	0.0050	0.0047	0.0047	0.0047	0.0047	0.0049
Silicon (Si)	mg/L	-	-	9	8	8	9	8	9	9	8	8	9	8	9	9	8	8	9	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.002	0.004	0.004	0.004	0.004	0.002	0.100	0.091	0.091	0.092	0.091	0.097
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.014	0.013	0.013	0.013	0.013	0.013

Notes

- 1
- World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.
- 2
- Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.
- 3
- Based on the un-ionized portion of ammonia.
- 4
- Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.
- 5
- Based on long-term exposure.
- 6
- Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.
- 7
- Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.
- 8
- Based on an alkalinity value of less than 60 mg/L.
- 9
- Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).
- 10
- Based on the dissolved form of this metal.
- 11
- Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.
- 12
- Based on a dissolved saturation of at least 80%.
- 13
- Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.
-
- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-12 Water Quality Results From Mine Area 10,000 m Downstream of Clarification Pond Outlets

Antsahalava River 10,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	31	30	31	31	33	33	31	30	31	31	33	33	31	31	31	31	33	45	42	42	42	42	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.16	0.16	0.16	0.16	0.17	0.18	0.16	0.16	0.16	0.16	0.17	0.18	0.16	0.16	0.16	0.16	0.17	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.1	3.1	3.1	3.1	3.2	3.2	3.1	3.1	3.1	3.1	3.2	3.2	3.1	3.1	3.1	3.1	3.2	2.6	2.6	2.6	2.6	2.6	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	7	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.9	0.8	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.8	0.8	0.9	0.8	0.7	0.7	0.7	0.7	0.8
Sodium (Na)	mg/L	-	-	1.3	1.4	1.5	1.4	1.4	1.3	1.3	1.4	1.5	1.4	1.4	1.3	1.3	1.4	1.5	1.4	1.4	1.3	2.8	2.8	2.8	2.8	2.8	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0474	0.0463	0.0470	0.0467	0.0499	0.0500	0.0475	0.0464	0.0471	0.0468	0.0499	0.0500	0.0475	0.0465	0.0472	0.0469	0.0499	0.0003	0.0007	0.0008	0.0008	0.0008	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0054	0.0053	0.0053	0.0053	0.0054	0.0055	0.0054	0.0053	0.0053	0.0053	0.0054	0.0055	0.0054	0.0053	0.0054	0.0053	0.0054	0.0002	0.0004	0.0005	0.0004	0.0004	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.035	0.042	0.037	0.039	0.025	0.025	0.035	0.041	0.037	0.039	0.025	0.025	0.035	0.041	0.036	0.038	0.025	0.013	0.023	0.028	0.024	0.026	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.005	0.005	0.005	0.005	0.005	0.004	
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0047	0.0046	0.0047	0.0047	0.0050	0.0050	0.0047	0.0046	0.0047	0.0047	0.0050	0.0050	0.0047	0.0046	0.0047	0.0047	0.0050	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.009	0.010	0.009	0.010	0.006	0.006	0.009	0.010	0.009	0.009	0.006	0.006	0.009	0.009	0.009	0.009	0.006	0.008	0.011	0.011	0.010	0.011	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.4	1.3	1.3	1.3	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.047	0.046	0.047	0.046	0.050	0.050	0.047	0.046	0.047	0.047	0.050	0.050	0.047	0.046	0.047	0.047	0.050	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0013	0.0016	0.0013	0.0014	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.007	0.008	0.007	0.008	0.008	0.008	0.007	0.008	0.007	0.008	0.008	0.008	0.007	0.008	0.008	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0049	0.0049	0.0049	0.0049	0.0050	0.0050	0.0049	0.0049	0.0049	0.0049	0.0050	0.0050	0.0049	0.0049	0.0049	0.0049	0.0050	0.0001	0.0003	0.0004	0.0003	0.0003	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	9	8	9	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.095	0.093	0.094	0.093	0.100	0.100	0.095	0.093	0.094	0.094	0.100	0.100	0.095	0.093	0.094	0.094	0.100	0.002	0.003	0.003	0.003	0.003	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.014	0.014	0.013	0.013	0.013	0.014	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-12 Water Quality Results From Mine Area 10,000 m Downstream of Clarification Pond Outlets (continued)

Sahamarirana River 10,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	30	30	31	30	32	33	30	30	31	30	32	33	30	30	31	30	32	45	41	41	42	42	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.16	0.16	0.16	0.16	0.17	0.18	0.16	0.16	0.16	0.16	0.17	0.18	0.16	0.16	0.16	0.16	0.17	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.3	1.4	1.3	1.3	1.4	1.4	1.4	1.4	1.3	1.3	1.4	1.4	1.4	1.4	1.3	1.3	1.4	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.0	3.0	3.0	3.0	3.1	3.2	3.0	3.0	3.0	3.0	3.1	3.2	3.0	3.0	3.0	3.0	3.1	2.6	2.5	2.5	2.5	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	6	6	7	7	7	7	6	6	7	7	7	7	6	6	7	7	7	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.9	0.8	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.8	0.8	0.9	0.8	0.7	0.7	0.7	0.7	0.7
Sodium (Na)	mg/L	-	-	1.3	1.3	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.3	1.4	1.3	1.3	1.3	2.8	2.7	2.7	2.7	2.7	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2	2	1	1	2	2	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0458	0.0454	0.0466	0.0463	0.0489	0.0500	0.0459	0.0455	0.0466	0.0464	0.0489	0.0500	0.0459	0.0457	0.0467	0.0464	0.0489	0.0003	0.0008	0.0008	0.0007	0.0007	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0052	0.0052	0.0052	0.0052	0.0053	0.0055	0.0052	0.0052	0.0052	0.0052	0.0053	0.0055	0.0052	0.0052	0.0052	0.0052	0.0053	0.0002	0.0004	0.0004	0.0003	0.0003	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.033	0.035	0.029	0.030	0.024	0.025	0.033	0.035	0.029	0.030	0.024	0.025	0.033	0.034	0.029	0.030	0.024	0.013	0.022	0.023	0.017	0.018	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0046	0.0045	0.0047	0.0046	0.0049	0.0050	0.0046	0.0045	0.0047	0.0046	0.0049	0.0050	0.0046	0.0046	0.0047	0.0046	0.0049	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.010	0.010	0.008	0.007	0.006	0.006	0.010	0.010	0.008	0.007	0.006	0.006	0.010	0.010	0.008	0.007	0.006	0.008	0.011	0.011	0.009	0.008	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.0	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1	1.1	1.1	1.1	1.0	1.0	1.1	1.1	1.1	1.4	1.3	1.3	1.3	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.046	0.045	0.046	0.046	0.049	0.050	0.046	0.045	0.047	0.046	0.049	0.050	0.046	0.045	0.047	0.046	0.049	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.07	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0013	0.0013	0.0008	0.0008	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0048	0.0048	0.0047	0.0047	0.0049	0.0050	0.0048	0.0048	0.0048	0.0047	0.0049	0.0050	0.0048	0.0048	0.0048	0.0047	0.0049	0.0001	0.0003	0.0003	0.0002	0.0002	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	8	8	8	8	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.092	0.091	0.093	0.093	0.098	0.100	0.092	0.091	0.093	0.093	0.098	0.100	0.092	0.091	0.093	0.093	0.098	0.002	0.003	0.003	0.003	0.003	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.013	0.013	0.013	0.013	0.013	0.014	0.013	0.013	0.013	0.013	0.013	0.014	0.013	0.013	0.013	0.013	0.013	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-12 Water Quality Results From Mine Area 10,000 m Downstream of Clarification Pond Outlets (continued)

Ankaja River 10,000 m downstream from outlet		Guidelines		January						February						March						April					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	33	31	31	31	31	32	33	31	31	31	31	32	33	31	31	31	31	32	45	42	42	43	42	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.18	0.16	0.16	0.17	0.16	0.17	0.18	0.16	0.17	0.17	0.16	0.17	0.18	0.16	0.17	0.17	0.16	0.17	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	3.2	3.1	3.1	3.1	3.1	3.2	3.2	3.1	3.1	3.1	3.1	3.2	3.2	3.1	3.1	3.1	3.1	3.2	2.6	2.5	2.5	2.6	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.9	0.8	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.9	0.8	0.9	0.8	0.7	0.7	0.7	0.7	0.7
Sodium (Na)	mg/L	-	-	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	2.8	2.6	2.6	2.7	2.6	2.7
Sulphate (SO ₄)	mg/L	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0500	0.0475	0.0475	0.0476	0.0473	0.0492	0.0500	0.0475	0.0476	0.0477	0.0473	0.0492	0.0500	0.0475	0.0476	0.0478	0.0473	0.0492	0.0003	0.0008	0.0008	0.0007	0.0009	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0055	0.0053	0.0053	0.0053	0.0053	0.0054	0.0055	0.0053	0.0053	0.0053	0.0053	0.0054	0.0055	0.0053	0.0053	0.0053	0.0053	0.0054	0.0002	0.0003	0.0003	0.0002	0.0003	0.0002
Barium (Ba)	mg/L	0.7	-	0.025	0.029	0.029	0.028	0.029	0.025	0.025	0.029	0.028	0.028	0.029	0.025	0.025	0.029	0.028	0.027	0.029	0.025	0.013	0.018	0.017	0.013	0.018	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.007	0.006	0.006	0.006	0.006	0.007	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0050	0.0047	0.0047	0.0048	0.0047	0.0049	0.0050	0.0047	0.0048	0.0048	0.0047	0.0049	0.0050	0.0047	0.0048	0.0048	0.0047	0.0049	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.006	0.016	0.015	0.015	0.017	0.006	0.006	0.016	0.014	0.014	0.017	0.006	0.006	0.016	0.014	0.013	0.017	0.006	0.008	0.017	0.015	0.008	0.018	0.008
Cobalt (Co)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.005
Iron (Fe)	mg/L	-	-	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.4	1.3	1.3	1.4	1.3	1.4	
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.050	0.047	0.047	0.048	0.047	0.049	0.050	0.047	0.048	0.048	0.047	0.049	0.050	0.047	0.048	0.048	0.047	0.049	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0005	0.0010	0.0009	0.0005	0.0010	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.007	0.007	0.008	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0050	0.0049	0.0049	0.0049	0.0049	0.0049	0.0050	0.0049	0.0049	0.0049	0.0049	0.0049	0.0050	0.0049	0.0049	0.0049	0.0049	0.0049	0.0001	0.0002	0.0002	0.0001	0.0003	0.0001
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	9	9	9	9	9
Thallium (Tl)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.100	0.095	0.095	0.095	0.095	0.098	0.100	0.095	0.095	0.095	0.095	0.098	0.100	0.095	0.095	0.096	0.095	0.098	0.002	0.003	0.003	0.003	0.003	0.002
Vanadium (V)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.014	0.013	0.013	0.013	0.013	0.014	0.014	0.013	0.013	0.013	0.013	0.014	0.014	0.013	0.013	0.013	0.013	0.014	0.003	0.003	0.003	0.002	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-12 Water Quality Results From Mine Area 10,000 m Downstream of Clarification Pond Outlets (continued)

Antsahalava River 10,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	42	42	42	42	44	45	42	42	42	42	44	45	42	42	42	42	44	45	42	42	42	42	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.8	
Sodium (Na)	mg/L	-	-	2.8	2.8	2.8	2.8	2.8	2.7	2.8	2.8	2.8	2.8	2.8	2.7	2.8	2.8	2.8	2.8	2.8	2.7	2.8	2.8	2.8	2.8	2.7	
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0007	0.0008	0.0008	0.0008	0.0003	0.0003	0.0007	0.0008	0.0008	0.0008	0.0003	0.0003	0.0007	0.0008	0.0008	0.0008	0.0003	0.0003	0.0007	0.0008	0.0008	0.0003	
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0004	0.0005	0.0004	0.0004	0.0002	0.0002	0.0004	0.0005	0.0004	0.0004	0.0002	0.0002	0.0004	0.0005	0.0004	0.0004	0.0002	0.0002	0.0004	0.0005	0.0004	0.0002	
Barium (Ba)	mg/L	0.7	-	0.013	0.023	0.028	0.024	0.026	0.013	0.013	0.023	0.028	0.024	0.026	0.013	0.013	0.023	0.028	0.024	0.026	0.013	0.013	0.023	0.028	0.024	0.026	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.004	
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.011	0.011	0.010	0.011	0.008	0.008	0.011	0.011	0.010	0.011	0.008	0.008	0.011	0.011	0.010	0.011	0.008	0.008	0.011	0.011	0.010	0.011	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.4	
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0013	0.0016	0.0013	0.0014	0.0005	0.0005	0.0013	0.0016	0.0013	0.0014	0.0005	0.0005	0.0013	0.0016	0.0013	0.0014	0.0005	0.0005	0.0013	0.0016	0.0013	0.0014	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0003	0.0004	0.0003	0.0003	0.0001	0.0001	0.0003	0.0004	0.0003	0.0003	0.0001	0.0001	0.0003	0.0004	0.0003	0.0003	0.0001	0.0001	0.0003	0.0004	0.0003	0.0003	0.0001
Silicon (Si)	mg/L	-	-	9	9	8	9	8	9	9	9	8	9	8	9	9	9	8	9	8	9	9	9	8	9	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-12 Water Quality Results From Mine Area 10,000 m Downstream of Clarification Pond Outlets (continued)

Sahamarirana River 10,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	41	41	42	42	44	45	41	41	42	42	44	45	41	41	42	42	44	45	41	41	42	42	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7
Sodium (Na)	mg/L	-	-	2.8	2.7	2.7	2.7	2.7	2.7	2.8	2.7	2.7	2.7	2.7	2.7	2.8	2.7	2.7	2.7	2.7	2.7	2.8	2.7	2.7	2.7	2.7	2.7
Sulphate (SO ₄)	mg/L	-	-	1	2	2	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0008	0.0008	0.0007	0.0007	0.0003	0.0003	0.0008	0.0008	0.0007	0.0007	0.0003	0.0003	0.0008	0.0008	0.0007	0.0007	0.0003	0.0003	0.0008	0.0008	0.0007	0.0007	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0004	0.0004	0.0003	0.0003	0.0002	0.0002	0.0004	0.0004	0.0003	0.0003	0.0002	0.0002	0.0004	0.0004	0.0003	0.0003	0.0002	0.0002	0.0004	0.0004	0.0003	0.0003	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.022	0.023	0.017	0.018	0.013	0.013	0.022	0.023	0.017	0.018	0.013	0.013	0.022	0.023	0.017	0.018	0.013	0.013	0.022	0.023	0.017	0.018	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.011	0.011	0.009	0.008	0.008	0.008	0.011	0.011	0.009	0.008	0.008	0.008	0.011	0.011	0.009	0.008	0.008	0.008	0.011	0.011	0.009	0.008	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0013	0.0013	0.0008	0.0008	0.0005	0.0005	0.0013	0.0013	0.0008	0.0008	0.0005	0.0005	0.0013	0.0013	0.0008	0.0008	0.0005	0.0005	0.0013	0.0013	0.0008	0.0008	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0003	0.0003	0.0002	0.0002	0.0001	0.0001	0.0003	0.0003	0.0002	0.0002	0.0001	0.0001	0.0003	0.0003	0.0002	0.0002	0.0001	0.0001	0.0003	0.0003	0.0002	0.0002	0.0001
Silicon (Si)	mg/L	-	-	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-12 Water Quality Results From Mine Area 10,000 m Downstream of Clarification Pond Outlets (continued)

Ankaja River 10,000 m downstream from outlet		Guidelines		May						June						July						August					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	42	42	43	42	44	45	42	42	43	42	44	45	42	42	43	42	44	45	42	42	43	42	44
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Chloride (Cl)	mg/L	-	-	2.6	2.5	2.5	2.6	2.5	2.6	2.6	2.5	2.5	2.6	2.5	2.6	2.6	2.5	2.5	2.6	2.5	2.6	2.6	2.5	2.5	2.6	2.5	2.6
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7
Sodium (Na)	mg/L	-	-	2.8	2.6	2.6	2.7	2.6	2.7	2.8	2.6	2.6	2.7	2.6	2.7	2.8	2.6	2.6	2.7	2.6	2.7	2.8	2.6	2.6	2.7	2.6	2.7
Sulphate (SO ₄)	mg/L	-	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0008	0.0008	0.0007	0.0009	0.0003	0.0003	0.0008	0.0008	0.0007	0.0009	0.0003	0.0003	0.0008	0.0008	0.0007	0.0009	0.0003	0.0003	0.0008	0.0008	0.0007	0.0009	0.0003
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0003	0.0003	0.0002	0.0003	0.0002	0.0002	0.0003	0.0003	0.0002	0.0003	0.0002	0.0002	0.0003	0.0003	0.0002	0.0003	0.0002	0.0002	0.0003	0.0003	0.0002	0.0003	0.0002
Barium (Ba)	mg/L	0.7	-	0.013	0.018	0.017	0.013	0.018	0.013	0.013	0.018	0.017	0.013	0.018	0.013	0.013	0.018	0.017	0.013	0.018	0.013	0.013	0.018	0.017	0.013	0.018	0.013
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.017	0.015	0.008	0.018	0.008	0.008	0.017	0.015	0.008	0.018	0.008	0.008	0.017	0.015	0.008	0.018	0.008	0.008	0.017	0.015	0.008	0.018	0.008
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005
Iron (Fe)	mg/L	-	-	1.4	1.3	1.3	1.4	1.3	1.4	1.4	1.3	1.3	1.4	1.3	1.4	1.4	1.3	1.3	1.4	1.3	1.4	1.4	1.3	1.3	1.4	1.3	1.4
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0010	0.0009	0.0005	0.0010	0.0005	0.0005	0.0010	0.0009	0.0005	0.0010	0.0005	0.0005	0.0010	0.0009	0.0005	0.0010	0.0005	0.0005	0.0010	0.0009	0.0005	0.0010	0.0005
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.008	0.007	0.008	0.008	0.007	0.007	0.008	0.007	0.008	0.008	0.007	0.007	0.008	0.007	0.008	0.008	0.007	0.007	0.008	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0002	0.0002	0.0001	0.0003	0.0001	0.0001	0.0002	0.0002	0.0001	0.0003	0.0001	0.0001	0.0002	0.0002	0.0001	0.0003	0.0001	0.0001	0.0002	0.0002	0.0001	0.0003	0.0001
Silicon (Si)	mg/L	-	-	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-12 Water Quality Results From Mine Area 10,000 m Downstream of Clarification Pond Outlets (continued)

Antsahalava River 10,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	42	42	42	42	44	45	42	42	42	42	44	45	42	42	42	42	44	33	31	30	31	31	33
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.18	0.16	0.16	0.16	0.16	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.4	1.4	1.4	1.4	1.4	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	3.2	3.1	3.1	3.1	3.1	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7	7	7	7	7	7
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.9	0.8	0.8	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.8	2.8	2.8	2.8	2.7	2.8	2.8	2.8	2.8	2.8	2.7	2.8	2.8	2.8	2.8	2.8	2.7	1.3	1.4	1.5	1.4	1.4	1.3
Sulphate (SO ₄)	mg/L	-	-	1	2	2	2	2	1	1	2	2	2	2	1	1	2	2	2	2	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0007	0.0008	0.0008	0.0008	0.0003	0.0003	0.0007	0.0008	0.0008	0.0008	0.0003	0.0003	0.0007	0.0008	0.0008	0.0008	0.0003	0.0500	0.0475	0.0464	0.0471	0.0468	0.0499
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0004	0.0005	0.0004	0.0004	0.0002	0.0002	0.0004	0.0005	0.0004	0.0004	0.0002	0.0002	0.0004	0.0005	0.0004	0.0004	0.0002	0.0055	0.0054	0.0053	0.0053	0.0053	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.023	0.028	0.024	0.026	0.013	0.013	0.023	0.028	0.024	0.026	0.013	0.013	0.023	0.028	0.024	0.026	0.013	0.025	0.035	0.041	0.037	0.039	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.007	0.007	0.007	0.007	0.007	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0047	0.0046	0.0047	0.0047	0.0050
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.011	0.011	0.010	0.011	0.008	0.008	0.011	0.011	0.010	0.011	0.008	0.008	0.011	0.011	0.010	0.011	0.008	0.006	0.009	0.010	0.009	0.009	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Iron (Fe)	mg/L	-	-	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.1	1.1	1.1	1.1	1.1	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.047	0.046	0.047	0.047	0.050
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0013	0.0016	0.0013	0.0014	0.0005	0.0005	0.0013	0.0016	0.0013	0.0014	0.0005	0.0005	0.0013	0.0016	0.0013	0.0014	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.008	0.007	0.008	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0003	0.0004	0.0003	0.0003	0.0001	0.0001	0.0003	0.0004	0.0003	0.0003	0.0001	0.0001	0.0003	0.0004	0.0003	0.0003	0.0001	0.0050	0.0049	0.0049	0.0049	0.0049	0.0050
Silicon (Si)	mg/L	-	-	9	9	8	9	8	9	9	9	8	9	8	9	9	9	8	9	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.100	0.095	0.093	0.094	0.094	0.100
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.014	0.014	0.013	0.013	0.013	0.014

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-12 Water Quality Results From Mine Area 10,000 m Downstream of Clarification Pond Outlets (continued)

Sahamarirana River 10,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	41	41	42	42	44	45	41	41	42	42	44	45	41	41	42	42	44	33	30	30	31	30	32
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.18	0.16	0.16	0.16	0.16	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.4	1.4	1.4	1.3	1.3	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5	2.6	3.2	3.0	3.0	3.0	3.0	3.1
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7	6	6	7	7	7
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.9	0.8	0.8	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.7	2.7	2.7	2.7	2.7	2.8	2.7	2.7	2.7	2.7	2.7	2.8	2.7	2.7	2.7	2.7	2.7	1.3	1.3	1.4	1.3	1.3	1.3
Sulphate (SO ₄)	mg/L	-	-	1	2	2	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1	2	2	2	2	2	1
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0008	0.0008	0.0007	0.0007	0.0003	0.0003	0.0008	0.0008	0.0007	0.0007	0.0003	0.0003	0.0008	0.0008	0.0007	0.0007	0.0003	0.0500	0.0459	0.0455	0.0466	0.0464	0.0489
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0004	0.0004	0.0003	0.0003	0.0002	0.0002	0.0004	0.0004	0.0003	0.0003	0.0002	0.0002	0.0004	0.0004	0.0003	0.0003	0.0002	0.0055	0.0052	0.0052	0.0052	0.0052	0.0053
Barium (Ba)	mg/L	0.7	-	0.013	0.022	0.023	0.017	0.018	0.013	0.013	0.022	0.023	0.017	0.018	0.013	0.013	0.022	0.023	0.017	0.018	0.013	0.025	0.033	0.035	0.029	0.030	0.024
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.006	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0046	0.0045	0.0047	0.0046	0.0049
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.011	0.011	0.009	0.008	0.008	0.008	0.011	0.011	0.009	0.008	0.008	0.008	0.011	0.011	0.009	0.008	0.008	0.006	0.010	0.010	0.008	0.007	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Iron (Fe)	mg/L	-	-	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.1	1.0	1.0	1.1	1.1	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.046	0.045	0.047	0.046	0.049
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0013	0.0013	0.0008	0.0008	0.0005	0.0005	0.0013	0.0013	0.0008	0.0008	0.0005	0.0005	0.0013	0.0013	0.0008	0.0008	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008	0.008	0.007	0.007	0.007	0.007	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0003	0.0003	0.0002	0.0002	0.0001	0.0001	0.0003	0.0003	0.0002	0.0002	0.0001	0.0001	0.0003	0.0003	0.0002	0.0002	0.0001	0.0050	0.0048	0.0048	0.0048	0.0047	0.0049
Silicon (Si)	mg/L	-	-	9	8	8	8	8	9	9	8	8	8	8	9	9	8	8	8	8	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.100	0.092	0.091	0.093	0.093	0.098
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.014	0.013	0.013	0.013	0.013	0.013

Notes

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Based on the un-ionized portion of ammonia.

4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

5

Based on long-term exposure.

6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.

7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).

10

Based on the dissolved form of this metal.

11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

12

Based on a dissolved saturation of at least 80%.

13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-12 Water Quality Results From Mine Area 10,000 m Downstream of Clarification Pond Outlets (continued)

Ankaja River 10,000 m downstream from outlet		Guidelines		September						October						November						December					
Water Quality Substance	Units	WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure	Baseline	Year 4	Year 10	Year 15	Year 20	Post-closure
Total Alkalinity as CaCO ₃	mg/L	-	-	45	42	42	43	42	44	45	42	42	43	42	44	45	42	42	43	42	44	33	31	31	31	31	32
Free and Saline Ammonia as N	mg/L	-	0.015 ³	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.18	0.16	0.17	0.17	0.16	0.17
Nitrate (NO ₃)	mg/L	50	-	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.4	1.4	1.4	1.4	1.4	1.4
Nitrite (NO ₂)	mg/L	0.2 ^{4,5}	-	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	2.6	2.5	2.5	2.6	2.5	2.6	2.6	2.5	2.5	2.6	2.5	2.6	2.6	2.5	2.5	2.6	2.5	2.6	3.2	3.1	3.1	3.1	3.1	3.2
Fluoride (F)	mg/L	1.5	1.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Magnesium (Mg)	mg/L	-	-	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7	7	7	7	7	7
Potassium (K)	mg/L	-	-	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.7	0.7	0.9	0.8	0.8	0.8	0.8	0.9
Sodium (Na)	mg/L	-	-	2.8	2.6	2.6	2.7	2.6	2.7	2.8	2.6	2.6	2.7	2.6	2.7	2.8	2.6	2.6	2.7	2.6	2.7	1.3	1.3	1.3	1.3	1.3	1.3
Sulphate (SO ₄)	mg/L	-	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2
Aluminium (Al)	mg/L	-	0.02 ⁶	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.03
Antimony (Sb)	mg/L	0.02	-	0.0003	0.0008	0.0008	0.0007	0.0009	0.0003	0.0003	0.0008	0.0008	0.0007	0.0009	0.0003	0.0003	0.0008	0.0008	0.0007	0.0009	0.0003	0.0500	0.0475	0.0476	0.0477	0.0473	0.0492
Arsenic (As)	mg/L	0.01 ⁴	0.02	0.0002	0.0003	0.0003	0.0002	0.0003	0.0002	0.0002	0.0003	0.0003	0.0002	0.0003	0.0002	0.0002	0.0003	0.0003	0.0002	0.0003	0.0002	0.0055	0.0053	0.0053	0.0053	0.0053	0.0054
Barium (Ba)	mg/L	0.7	-	0.013	0.018	0.017	0.013	0.018	0.013	0.013	0.018	0.017	0.013	0.018	0.013	0.013	0.018	0.017	0.013	0.018	0.013	0.025	0.029	0.028	0.028	0.029	0.025
Boron (B)	mg/L	0.5 ⁷	-	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.007	0.006	0.006	0.006	0.006	0.007
Cadmium (Cd)	mg/L	0.003	0.00015 ^{8,9}	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0050	0.0047	0.0048	0.0048	0.0047	0.0049
Chromium (Cr)	mg/L	0.05 ⁴	0.014 ^{10,11}	0.008	0.017	0.015	0.008	0.018	0.008	0.008	0.017	0.015	0.008	0.018	0.008	0.008	0.017	0.015	0.008	0.018	0.008	0.006	0.016	0.014	0.014	0.017	0.006
Cobalt (Co)	mg/L	-	-	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005
Copper (Cu)	mg/L	2	0.00053 ^{8,10}	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Iron (Fe)	mg/L	-	-	1.4	1.3	1.3	1.4	1.3	1.4	1.4	1.3	1.3	1.4	1.3	1.4	1.4	1.3	1.3	1.4	1.3	1.4	1.1	1.1	1.1	1.1	1.1	1.1
Lead (Pb)	mg/L	0.01	0.000475 ^{8,10,12}	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.047	0.048	0.048	0.047	0.049
Manganese (Mn)	mg/L	0.4 ¹³	0.37 ¹⁰	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Molybdenum (Mo)	mg/L	0.07	-	0.0005	0.0010	0.0009	0.0005	0.0010	0.0005	0.0005	0.0010	0.0009	0.0005	0.0010	0.0005	0.0005	0.0010	0.0009	0.0005	0.0010	0.0005	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.02 ⁴	-	0.008	0.007	0.007	0.008	0.007	0.008	0.008	0.007	0.007	0.008	0.007	0.008	0.008	0.007	0.007	0.008	0.007	0.008	0.008	0.008	0.008	0.008	0.008	0.008
Selenium (Se)	mg/L	0.01	0.005	0.0001	0.0002	0.0002	0.0001	0.0003	0.0001	0.0001	0.0002	0.0002	0.0001	0.0003	0.0001	0.0001	0.0002	0.0002	0.0001	0.0003	0.0001	0.0050	0.0049	0.0049	0.0049	0.0049	0.0049
Silicon (Si)	mg/L	-	-	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	-	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.004	-	-	-	-	-	-
Uranium (U)	mg/L	0.015 ^{4,7}	-	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.100	0.095	0.095	0.095	0.095	0.098
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005
Zinc (Zn)	mg/L	-	0.0036 ¹⁰	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.014	0.013	0.013	0.013	0.013	0.014

- Notes
- 1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.
- 2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.
- 3

Based on the un-ionized portion of ammonia.
- 4

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.
- 5

Based on long-term exposure.
- 6

Based on pH value greater than 6.5. Baseline values for pH range from 7.1 to 7.2. The predicted pH values of project-related runoff ranges range from 6.8 to 7.2.
- 7

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.
- 8

Based on an alkalinity value of less than 60 mg/L.
- 9

Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).
- 10

Based on the dissolved form of this metal.
- 11

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.
- 12

Based on a dissolved saturation of at least 80%.
- 13

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.
- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-13 Baseline and Maximum Predicted Sediment Quality Results From the Mine Area

Substance	Units	Baseline Sediment Concentration	Operations		Canadian Sediment Guidelines ¹	
			Maximum Sediment Concentration	Maximum Increase from Baseline	ISQG ²	PEL ³
Aluminum	mg/kg	25,000	25,000	0		
Antimony	mg/kg	0.47	0.52	0.05		
Arsenic	mg/kg	0.04	0.07	0.03	5.9	17
Barium	mg/kg	50.7	52.3	1.6		
Boron	mg/kg	0.014	0.014	0.0005		
Cadmium	mg/kg	0.21	0.21	0.003	0.6	3.5
Chromium	mg/kg	-	-	1.0	37.3	90
Cobalt	mg/kg	49	49	0.0002		
Copper	mg/kg	32	32	0	35.7	197
Lead	mg/kg	0.74	0.77	0.03	35	91.3
Manganese	mg/kg	743.8	743.8	0		
Mercury	mg/kg	0.0086	0.0087	0.00004	0.174	0.486
Nickel	mg/kg	672.8	672.8	0		
Selenium	mg/kg	0.01	0.02	0.008		
Thallium	mg/kg	0.08	0.13	0.05		
Vanadium	mg/kg	96.4	96.4	0.001		
Zinc	mg/kg	22.8	22.9	0.07	123	315
Iron	mg/kg	50580	50580	0		

Notes:

1 Canadian Sediment Quality Guidelines (updated February 2002).

2 ISQG = interim sediment quality guideline.

3 PEL = probable effects level.

- absolute concentrations are not presented because baseline chromium values of sediment concentrations were not available.

10 REFERENCES

United States Environmental Protection Agency (USEPA). 1999. Screening Level Ecological risk Assessment Protocol for Hazardous Waste Combustion facilities. Volume 1. Solid Waste and Emergency Response (5305W). USEPA, EPA530-D-99-001A.

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VOLUME I: PHYSICAL APPENDICES
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ATTACHMENT 2 – TAILINGS FACILITY

Submitted to:
Dynatec Corporation

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1 INTRODUCTION

This appendix presents additional information used or generated in Volume E, Section 3.10 (Water Quality Section of Tailings Facility Environmental Assessment [EA]) and includes:

- input values used in water quality modelling;
- inputs values used in sediment quality modelling;
- detailed results from the tailings water quality modelling; and
- detailed results from the tailings sediment quality modelling.

1.2 WATER QUALITY MODELLING INPUTS

Loads of combined clean groundwater and seepage loads of manganese for the basins that will receive tailings seepage directly were provided by Groundwater Consulting Services (PTY) Ltd. (2005) and are presented in Table 9.2-1.

Table 9.2-1 Combined Groundwater Loads of Manganese in Basins Receiving Direct Seepage From Tailings Facility (kg/day)

Basin	Baseline	Year 14	Year 20	Year 27	Post-Closure 15	Post-Closure 80
A1	0.08	0.82	1.19	1.86	1.73	0.79
B1	0.08	0.13	0.23	0.10	0.89	1.00
C1	0.04	0.04	0.05	0.06	1.20	0.49

Predicted effluent concentrations of the tailings effluent were provided by Dynatec Ltd. (S. Penttinen, pers. comm. 2005) and are presented in Table 9.2-2.

Table 9.2-2 Predicted Effluent Concentrations of the Tailings Effluent

Water Quality Variables or Substances	Units	Value
pH	pH units	8
conductivity	µS/cm	9,000
temperature	°C	25
total alkalinity as CaCO ₃	mg/L	87
total suspended solids	mg/L	100
total hardness as CaCO ₃	mg/L	9,530
free and saline ammonia as N	mg/L	0.1
nitrate (NO ₃)	mg/L	0.025
nitrite (NO ₂)	mg/L	0.03
Total phosphate (PO ₄)	mg/L	10
calcium (Ca)	mg/L	450
chloride (Cl)	mg/L	12
fluoride (F)	mg/L	1
magnesium (Mg)	mg/L	2,050
potassium (K)	mg/L	0.43
sodium (Na)	mg/L	5
sulphate (SO ₄)	mg/L	9,500
aluminum (Al)	mg/L	0.0015
antimony (Sb)	mg/L	0.005
arsenic (As)	mg/L	0.0005
barium (Ba)	mg/L	0.005
beryllium (Be)	mg/L	0.0005
bismuth, Bi	mg/L	0.0025
boron (B)	mg/L	0.0025
cadmium (Cd)	mg/L	0.0005
chromium (Cr)	mg/L	0.01
cobalt (Co)	mg/L	0.06
copper (Cu)	mg/L	0.009
iron (Fe)	mg/L	0.0015
lead (Pb)	mg/L	0.0025
manganese (Mn)	mg/L	230
mercury (Hg)	mg/L	0.0005
molybdenum (Mo)	mg/L	0.002
nickel (Ni)	mg/L	0.083
phosphorus (P)	mg/L	0.015
selenium (Se)	mg/L	0.01
silicon (Si)	mg/L	0.5
thallium (Tl)	mg/L	0.0001
tellurium (Te)	mg/L	0.05
vanadium (V)	mg/L	0.001
zinc (Zn)	mg/L	0.001
chronic toxicity	chronic toxicity unit	3.02

1.3 SEDIMENT MODELLING INPUTS

The equations for calculating substance concentration in benthic sediment are discussed in Volume I, Appendix 9.2, Attachment 1. Input values for watercourse characteristics and partition coefficients are provided in Tables 9.2-3 and 9.2-4, respectively.

Table 9.2-3 Characteristics of Watercourses Used for Sediment Modelling

Parameter	Units	Value for Tailings Area
pH	-	6 ^(a)
water depth	m	1 ^(b)
benthic sediment depth	m	0.03 ^(c)
total suspended solids	mg/L	6 ^(a)
bed sediment porosity	L water/L sediment	1 ^(c)
benthic sediment density	kg/L	1 ^(c)

^(a) Estimated based on observed source water values.

^(b) Estimated based on predicted water levels (Volume E, Section 3.8).

^(c) Default value used because predicted values were not available for this parameter and varying this input does not result in substantial changes in sediment concentration predictions.

Table 9.2-4 Partition Coefficients Used for Sediment Modelling

Substance	Suspended Solids - Surface Water, K_{dsw} , (L/kg) ^(a)	Bed sediment - Sediment Pore Water, K_{dbs} , (L/kg) ^(a)
aluminum	1.5×10^3	1.5×10^3
antimony	45	45
arsenic	29	29
barium	41	41
boron	3	3
cadmium	75	75
chromium	1.8×10^6	1.8×10^6
cobalt	45	45
copper	1.0×10^4	1.0×10^4
lead	900	900
manganese	19.4	19.4
mercury	3.0×10^3	3.0×10^3
nickel	65	65
selenium	5	5
thallium	71	71
vanadium	62	62
zinc	62	62
iron	25.1	25.1

^(a) US EPA 1999. Screening Level Ecological risk Assessment Protocol for Hazardous Waste Combustion facilities. Volume 1. Solid Waste and Emergency Response (5305W). US EPA, EPA530-D-99-001A.

1.4 WATER QUALITY RESULTS

Tables 9.2-5 to 9.2-16 present the detailed water quality modelling results for the tailings facility area.

1.5 SEDIMENT QUALITY RESULTS

Table 9.2-17 presents the detailed sediment quality modelling results for the tailings facility area.

Table 9.2-5 Water Quality Results From Basin A1

Water Quality Substance	Units	Guidelines		Dry Water Quality, Dry Flows						Wet Water Quality, Average Flows						Average Wet + Dry Water Quality, Average Flows					
		WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80
conductivity	µS/cm	-	-	44	55	53	56	57	51	40	44	43	44	44	43	42	45	45	46	46	44
total alkalinity as CaCO ₃	mg/L	-	-	18	14	7	7	5	7	8	7	4	4	4	5	10	8	6	6	6	6
nitrate (NO ₃)	mg/L	50	-	2.1	2.2	2.4	2.4	2.5	2.4	0.2	0.2	0.2	0.2	0.2	0.2	1.1	1.2	1.2	1.2	1.2	1.2
nitrite (NO ₂)	mg/L	0.2 ^{3,4}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
calcium (Ca)	mg/L	-	-	3	3	2	2	2	2	2	2	1	1	1	1	2	2	1	1	1	1
chloride (Cl)	mg/L	-	-	5.7	5.2	4.2	4.2	4.0	4.3	6.3	6.1	5.8	5.8	5.8	5.8	6.1	6.0	5.7	5.7	5.6	5.7
magnesium (Mg)	mg/L	-	-	2	3	2	3	2	2	1	1	1	1	1	1	1	2	1	1	1	1
sodium (Na)	mg/L	-	-	5.1	4.5	3.4	3.3	3.0	3.4	3.5	3.3	2.9	2.9	2.8	2.9	2.8	2.5	2.1	2.1	2.0	2.1
sulphate (SO ₄)	mg/L	-	-	4	14	10	13	13	8	2	5	4	5	5	3	3	6	5	6	6	4
aluminium (Al)	mg/L	-	0.01 ⁵	0.06	0.05	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.02
arsenic (As)	mg/L	0.01 ³	0.02	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
barium (Ba)	mg/L	0.7	-	0.009	0.008	0.006	0.006	0.005	0.006	0.025	0.025	0.025	0.025	0.025	0.025	0.017	0.016	0.016	0.016	0.016	0.016
chromium (Cr)	mg/L	0.05 ³	0.014 ^{6,7}	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
cobalt (Co)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
copper (Cu)	mg/L	2	0.00053 ^{6,8}	0.003	0.004	0.004	0.004	0.004	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.004	0.004
iron (Fe)	mg/L	-	-	2.1	2.2	2.4	2.4	2.5	2.4	1.2	1.3	1.3	1.3	1.3	1.3	1.6	1.7	1.7	1.7	1.7	1.7
lead (Pb)	mg/L	0.01	0.000475 ^{6,8,9}	0.005	0.005	0.005	0.005	0.005	0.005	0.051	0.052	0.053	0.053	0.054	0.053	0.026	0.027	0.028	0.028	0.028	0.027
manganese (Mn)	mg/L	0.4 ¹⁰	0.37 ¹¹	0.16	0.40	0.31	0.39	0.38	0.26	0.06	0.13	0.10	0.12	0.12	0.08	0.11	0.19	0.15	0.18	0.18	0.14
mercury (Hg)	mg/L	0.001	0.00008	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0025	0.0025	0.0026	0.0026	0.0026	0.0026	0.0012	0.0013	0.0013	0.0013	0.0013	0.0013
nickel (Ni)	mg/L	0.02 ³	-	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
silicon (Si)	mg/L	-	-	10.7	7.8	2.8	2.7	1.4	2.9	-	-	-	-	-	-	3.6	2.5	0.7	0.7	0.3	0.8
vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
zinc (Zn)	mg/L	-	0.0036 ⁶	0.79	0.58	0.22	0.22	0.12	0.23	0.28	0.20	0.07	0.07	0.04	0.08	0.28	0.20	0.07	0.07	0.04	0.08

1 World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2 Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3 Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

4 Based on long-term exposure.

5 Based on pH value less than 6.5. Baseline values for pH range from 6.1 to 6.2. The predicted pH value of the tailing seepage was 8.

6 Based on the dissolved form of this metal.

7 Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

8 Based on an alkalinity value of less than 60 mg/L.

9 Based on a dissolved saturation of at least 80%.

10 Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

11 Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

- 'No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-6 Water Quality Results From Basin A2

Water Quality Substance	Units	Guidelines		Dry Water Quality, Dry Flows						Wet Water Quality, Average Flows						Average Wet + Dry Water Quality, Average Flows					
		WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80
conductivity	µS/cm	-	-	44	49	51	53	53	49	40	42	42	43	43	42	42	44	44	45	45	43
total alkalinity as CaCO ₃	mg/L	-	-	18	17	11	10	9	11	8	8	6	6	5	6	10	10	7	7	7	7
nitrate (NO ₃)	mg/L	50	-	2.0	2.1	2.3	2.3	2.3	2.3	0.2	0.2	0.2	0.2	0.2	0.2	1.1	1.2	1.2	1.2	1.2	1.2
nitrite (NO ₂)	mg/L	0.2 ^{3,4}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
calcium (Ca)	mg/L	-	-	3	3	2	2	2	2	2	2	1	1	1	1	2	2	1	1	1	1
chloride (Cl)	mg/L	-	-	5.8	5.6	4.7	4.7	4.5	4.7	6.3	6.2	6.0	5.9	5.9	6.0	6.2	6.1	5.8	5.8	5.8	5.8
magnesium (Mg)	mg/L	-	-	2	3	2	3	2	2	1	1	1	1	1	1	1	2	1	1	1	1
sodium (Na)	mg/L	-	-	5.2	5.0	3.9	3.9	3.6	3.9	3.6	3.5	3.1	3.1	3.0	3.1	2.8	2.7	2.3	2.3	2.2	2.3
sulphate (SO ₄)	mg/L	-	-	4	9	8	11	11	7	2	4	3	4	4	3	3	5	4	5	5	4
aluminium (Al)	mg/L	-	0.01 ⁵	0.06	0.05	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02
arsenic (As)	mg/L	0.01 ³	0.02	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
barium (Ba)	mg/L	0.7	-	0.009	0.008	0.007	0.007	0.006	0.007	0.025	0.025	0.025	0.025	0.025	0.025	0.017	0.017	0.016	0.016	0.016	0.016
chromium (Cr)	mg/L	0.05 ³	0.014 ^{6,7}	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
cobalt (Co)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
copper (Cu)	mg/L	2	0.00053 ^{6,8}	0.003	0.003	0.004	0.004	0.004	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.004	0.004
iron (Fe)	mg/L	-	-	2.1	2.1	2.3	2.3	2.4	2.3	1.2	1.2	1.3	1.3	1.3	1.3	1.6	1.7	1.7	1.7	1.7	1.7
lead (Pb)	mg/L	0.01	0.000475 ^{6,8,9}	0.005	0.005	0.005	0.005	0.005	0.005	0.051	0.051	0.053	0.053	0.053	0.052	0.026	0.026	0.027	0.027	0.027	0.027
manganese (Mn)	mg/L	0.4 ¹⁰	0.37 ¹¹	0.16	0.29	0.27	0.33	0.32	0.23	0.06	0.10	0.09	0.11	0.10	0.08	0.11	0.15	0.14	0.16	0.16	0.13
mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0025	0.0025	0.0025	0.0025	0.0026	0.0025	0.0012	0.0012	0.0013	0.0013	0.0013	0.0013
nickel (Ni)	mg/L	0.02 ³	-	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
silicon (Si)	mg/L	-	-	11.1	10.0	5.4	5.3	4.1	5.4	-	-	-	-	-	-	3.8	3.3	1.6	1.6	1.2	1.6
vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
zinc (Zn)	mg/L	-	0.0036 ⁶	0.83	0.75	0.41	0.40	0.32	0.41	0.29	0.26	0.13	0.13	0.10	0.14	0.29	0.26	0.13	0.13	0.10	0.14

1 World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2 Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3 Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

4 Based on long-term exposure.

5 Based on pH value less than 6.5. Baseline values for pH range from 6.1 to 6.2. The predicted pH value of the tailing seepage was 8.

6 Based on the dissolved form of this metal.

7 Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

8 Based on an alkalinity value of less than 60 mg/L.

9 Based on a dissolved saturation of at least 80%.

10 Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

11 Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

- 'No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-7 Water Quality Results From Basin A3

Water Quality Substance	Units	Guidelines		Dry Water Quality, Dry Flows						Wet Water Quality, Average Flows						Average Wet + Dry Water Quality, Average Flows					
		WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80
conductivity	µS/cm	-	-	43	47	49	51	51	48	40	42	42	43	43	42	42	43	43	44	44	43
total alkalinity as CaCO ₃	mg/L	-	-	19	19	13	13	12	13	9	9	6	6	6	6	11	10	8	8	8	8
nitrate (NO ₃)	mg/L	50	-	2.0	2.0	2.2	2.2	2.2	2.2	0.2	0.2	0.2	0.2	0.2	0.2	1.1	1.1	1.2	1.2	1.2	1.2
nitrite (NO ₂)	mg/L	0.2 ^{3,4}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
calcium (Ca)	mg/L	-	-	3	4	3	3	2	2	2	2	1	1	1	1	2	2	1	1	1	1
chloride (Cl)	mg/L	-	-	6.0	5.9	5.1	5.0	4.9	5.1	6.3	6.3	6.0	6.0	6.0	6.0	6.2	6.2	5.9	5.9	5.9	5.9
magnesium (Mg)	mg/L	-	-	2	3	2	3	2	2	1	1	1	1	1	1	1	2	1	1	1	1
sodium (Na)	mg/L	-	-	5.4	5.4	4.3	4.3	4.1	4.3	3.6	3.6	3.2	3.2	3.1	3.2	2.9	2.9	2.5	2.5	2.4	2.5
sulphate (SO ₄)	mg/L	-	-	4	8	8	10	10	7	2	3	3	4	4	3	3	4	4	5	5	4
aluminium (Al)	mg/L	-	0.01 ⁵	0.06	0.06	0.05	0.05	0.04	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02
arsenic (As)	mg/L	0.01 ³	0.02	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
barium (Ba)	mg/L	0.7	-	0.009	0.009	0.007	0.007	0.007	0.007	0.025	0.025	0.025	0.025	0.025	0.025	0.017	0.017	0.016	0.016	0.016	0.016
chromium (Cr)	mg/L	0.05 ³	0.014 ^{6,7}	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
cobalt (Co)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
copper (Cu)	mg/L	2	0.00053 ^{6,8}	0.003	0.003	0.004	0.004	0.004	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.004	0.004
iron (Fe)	mg/L	-	-	2.0	2.0	2.2	2.2	2.3	2.2	1.2	1.2	1.3	1.3	1.3	1.3	1.6	1.6	1.7	1.7	1.7	1.7
lead (Pb)	mg/L	0.01	0.000475 ^{6,8,9}	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.050	0.052	0.052	0.052	0.052	0.026	0.026	0.027	0.027	0.027	0.027
manganese (Mn)	mg/L	0.4 ¹⁰	0.37 ¹¹	0.16	0.26	0.25	0.31	0.30	0.22	0.06	0.09	0.08	0.10	0.10	0.07	0.11	0.15	0.14	0.16	0.16	0.13
mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0024	0.0024	0.0025	0.0025	0.0025	0.0025	0.0012	0.0012	0.0013	0.0013	0.0013	0.0013
nickel (Ni)	mg/L	0.02 ³	-	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
silicon (Si)	mg/L	-	-	12.1	11.9	7.2	7.1	6.2	7.3	-	-	-	-	-	-	4.1	4.0	2.2	2.2	1.9	2.2
vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
zinc (Zn)	mg/L	-	0.0036 ⁶	0.90	0.88	0.54	0.54	0.47	0.55	0.32	0.31	0.18	0.18	0.15	0.18	0.32	0.31	0.18	0.18	0.15	0.18

1 World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2 Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3 Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

4 Based on long-term exposure.

5 Based on pH value less than 6.5. Baseline values for pH range from 6.1 to 6.2. The predicted pH value of the tailing seepage was 8.

6 Based on the dissolved form of this metal.

7 Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

8 Based on an alkalinity value of less than 60 mg/L.

9 Based on a dissolved saturation of at least 80%.

10 Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

11 Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

- 'No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-8 Water Quality Results From Basin A4

Water Quality Substance	Units	Guidelines		Dry Water Quality, Dry Flows						Wet Water Quality, Average Flows						Average Wet + Dry Water Quality, Average Flows					
		WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80
conductivity	µS/cm	-	-	43	46	48	50	51	47	40	41	42	43	43	42	42	43	43	44	44	43
total alkalinity as CaCO ₃	mg/L	-	-	20	20	14	14	13	14	9	9	7	7	6	7	11	11	8	8	8	8
nitrate (NO ₃)	mg/L	50	-	2.0	2.0	2.2	2.2	2.2	2.2	0.2	0.2	0.2	0.2	0.2	0.2	1.1	1.1	1.2	1.2	1.2	1.2
nitrite (NO ₂)	mg/L	0.2 ^{3,4}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
calcium (Ca)	mg/L	-	-	3	4	3	3	3	3	2	2	1	1	1	1	2	2	2	2	1	1
chloride (Cl)	mg/L	-	-	6.0	6.0	5.2	5.2	5.0	5.2	6.3	6.3	6.1	6.1	6.0	6.1	6.2	6.2	6.0	6.0	5.9	6.0
magnesium (Mg)	mg/L	-	-	2	3	2	3	2	2	1	1	1	1	1	1	1	2	1	1	1	1
sodium (Na)	mg/L	-	-	5.5	5.4	4.5	4.5	4.3	4.5	3.7	3.6	3.3	3.3	3.2	3.3	2.9	2.9	2.5	2.5	2.4	2.5
sulphate (SO ₄)	mg/L	-	-	4	7	7	9	9	6	2	3	3	4	4	3	3	4	4	5	5	4
aluminium (Al)	mg/L	-	0.01 ⁵	0.06	0.06	0.05	0.05	0.04	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02
arsenic (As)	mg/L	0.01 ³	0.02	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
barium (Ba)	mg/L	0.7	-	0.009	0.009	0.008	0.008	0.007	0.008	0.025	0.025	0.025	0.025	0.025	0.025	0.017	0.017	0.016	0.016	0.016	0.016
chromium (Cr)	mg/L	0.05 ³	0.014 ^{6,7}	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
cobalt (Co)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
copper (Cu)	mg/L	2	0.00053 ^{6,8}	0.003	0.003	0.004	0.004	0.004	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.004	0.004
iron (Fe)	mg/L	-	-	2.0	2.0	2.2	2.2	2.2	2.2	1.2	1.2	1.3	1.3	1.3	1.3	1.6	1.6	1.7	1.7	1.7	1.7
lead (Pb)	mg/L	0.01	0.000475 ^{6,8,9}	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.050	0.052	0.052	0.052	0.052	0.026	0.026	0.027	0.027	0.027	0.027
manganese (Mn)	mg/L	0.4 ¹⁰	0.37 ¹¹	0.16	0.24	0.24	0.29	0.29	0.22	0.06	0.09	0.08	0.10	0.09	0.07	0.11	0.14	0.14	0.15	0.15	0.13
mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0024	0.0024	0.0025	0.0025	0.0025	0.0025	0.0012	0.0012	0.0013	0.0013	0.0013	0.0013
nickel (Ni)	mg/L	0.02 ³	-	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
silicon (Si)	mg/L	-	-	12.3	12.1	7.8	7.8	6.9	7.9	-	-	-	-	-	-	4.2	4.1	2.4	2.4	2.1	2.5
vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
zinc (Zn)	mg/L	-	0.0036 ⁶	0.91	0.90	0.59	0.58	0.52	0.59	0.32	0.32	0.20	0.19	0.17	0.20	0.32	0.32	0.20	0.19	0.17	0.20

1 World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2 Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3 Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

4 Based on long-term exposure.

5 Based on pH value less than 6.5. Baseline values for pH range from 6.1 to 6.2. The predicted pH value of the tailing seepage was 8.

6 Based on the dissolved form of this metal.

7 Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

8 Based on an alkalinity value of less than 60 mg/L.

9 Based on a dissolved saturation of at least 80%.

10 Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

11 Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

- 'No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-9 Water Quality Results From Basin A5

Water Quality Substance	Units	Guidelines		Dry Water Quality, Dry Flows						Wet Water Quality, Average Flows						Average Wet + Dry Water Quality, Average Flows					
		WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80
conductivity	µS/cm	-	-	43	45	47	48	50	48	40	41	41	42	42	42	42	42	43	43	44	43
total alkalinity as CaCO ₃	mg/L	-	-	20	19	16	16	13	15	9	9	7	7	6	7	11	10	9	9	8	9
nitrate (NO ₃)	mg/L	50	-	2.0	2.0	2.1	2.1	2.2	2.1	0.2	0.2	0.2	0.2	0.2	0.2	1.1	1.1	1.2	1.2	1.2	1.2
nitrite (NO ₂)	mg/L	0.2 ^{3,4}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
calcium (Ca)	mg/L	-	-	4	3	3	3	2	3	2	2	1	2	1	1	2	2	2	2	1	2
chloride (Cl)	mg/L	-	-	6.1	5.9	5.4	5.5	5.0	5.4	6.4	6.3	6.2	6.2	6.0	6.1	6.2	6.2	6.0	6.0	5.9	6.0
magnesium (Mg)	mg/L	-	-	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1
sodium (Na)	mg/L	-	-	5.6	5.3	4.8	4.8	4.3	4.7	3.7	3.6	3.4	3.4	3.2	3.3	3.0	2.9	2.6	2.7	2.4	2.6
sulphate (SO ₄)	mg/L	-	-	4	6	7	8	9	7	2	3	3	3	3	3	3	4	4	4	5	4
aluminium (Al)	mg/L	-	0.01 ⁵	0.06	0.06	0.05	0.05	0.04	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02
arsenic (As)	mg/L	0.01 ³	0.02	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
barium (Ba)	mg/L	0.7	-	0.009	0.009	0.008	0.008	0.007	0.008	0.025	0.025	0.025	0.025	0.025	0.025	0.017	0.017	0.016	0.016	0.016	0.016
chromium (Cr)	mg/L	0.05 ³	0.014 ^{6,7}	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
cobalt (Co)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
copper (Cu)	mg/L	2	0.00053 ^{6,8}	0.003	0.003	0.003	0.003	0.004	0.003	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.004	0.004
iron (Fe)	mg/L	-	-	2.0	2.0	2.1	2.1	2.2	2.2	1.2	1.2	1.3	1.3	1.3	1.3	1.6	1.6	1.7	1.7	1.7	1.7
lead (Pb)	mg/L	0.01	0.000475 ^{6,8,9}	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.051	0.051	0.051	0.052	0.051	0.026	0.026	0.027	0.027	0.027	0.027
manganese (Mn)	mg/L	0.4 ¹⁰	0.37 ¹¹	0.16	0.21	0.22	0.25	0.28	0.23	0.06	0.07	0.08	0.09	0.09	0.08	0.11	0.13	0.13	0.14	0.15	0.13
mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0024	0.0025	0.0025	0.0025	0.0025	0.0025	0.0012	0.0012	0.0012	0.0012	0.0013	0.0012
nickel (Ni)	mg/L	0.02 ³	-	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
silicon (Si)	mg/L	-	-	12.7	11.6	9.3	9.4	6.8	8.9	-	-	-	-	-	-	4.3	3.9	3.0	3.0	2.1	2.8
vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
zinc (Zn)	mg/L	-	0.0036 ⁶	0.94	0.86	0.69	0.70	0.51	0.66	0.33	0.30	0.23	0.24	0.17	0.22	0.33	0.30	0.23	0.24	0.17	0.22

1 World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2 Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3 Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

4 Based on long-term exposure.

5 Based on pH value less than 6.5. Baseline values for pH range from 6.1 to 6.2. The predicted pH value of the tailing seepage was 8.

6 Based on the dissolved form of this metal.

7 Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

8 Based on an alkalinity value of less than 60 mg/L.

9 Based on a dissolved saturation of at least 80%.

10 Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

11 Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

- 'No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-10 Water Quality Results From Basin A6

Water Quality Substance	Units	Guidelines		Dry Water Quality, Dry Flows						Wet Water Quality, Average Flows						Average Wet + Dry Water Quality, Average Flows					
		WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80
conductivity	µS/cm	-	-	43	44	46	47	50	47	40	41	41	41	42	41	41	42	42	43	44	43
total alkalinity as CaCO ₃	mg/L	-	-	21	20	18	16	13	16	9	9	8	7	6	7	11	11	10	9	8	9
nitrate (NO ₃)	mg/L	50	-	2.0	2.0	2.1	2.1	2.2	2.1	0.2	0.2	0.2	0.2	0.2	0.2	1.1	1.1	1.2	1.2	1.2	1.2
nitrite (NO ₂)	mg/L	0.2 ^{3,4}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
calcium (Ca)	mg/L	-	-	4	4	3	3	3	3	2	2	2	2	1	1	2	2	2	2	1	2
chloride (Cl)	mg/L	-	-	6.2	6.1	5.7	5.5	5.1	5.4	6.4	6.4	6.2	6.2	6.0	6.2	6.3	6.2	6.1	6.0	5.9	6.0
magnesium (Mg)	mg/L	-	-	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1
sodium (Na)	mg/L	-	-	5.7	5.6	5.1	4.9	4.3	4.8	3.7	3.7	3.5	3.4	3.2	3.4	3.0	3.0	2.8	2.7	2.5	2.6
sulphate (SO ₄)	mg/L	-	-	4	5	6	7	9	6	2	2	3	3	3	3	3	4	4	4	5	4
aluminium (Al)	mg/L	-	0.01 ⁵	0.06	0.06	0.06	0.05	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02
arsenic (As)	mg/L	0.01 ³	0.02	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
barium (Ba)	mg/L	0.7	-	0.009	0.009	0.009	0.008	0.007	0.008	0.025	0.025	0.025	0.025	0.025	0.025	0.017	0.017	0.017	0.016	0.016	0.016
chromium (Cr)	mg/L	0.05 ³	0.014 ^{6,7}	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
cobalt (Co)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
copper (Cu)	mg/L	2	0.0005 ^{3,8}	0.003	0.003	0.003	0.003	0.004	0.003	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.004	0.004
iron (Fe)	mg/L	-	-	2.0	2.0	2.1	2.1	2.2	2.1	1.2	1.2	1.2	1.3	1.3	1.3	1.6	1.6	1.6	1.7	1.7	1.7
lead (Pb)	mg/L	0.01	0.000475 ^{6,8,9}	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.050	0.051	0.051	0.052	0.051	0.026	0.026	0.026	0.027	0.027	0.027
manganese (Mn)	mg/L	0.4 ¹⁰	0.37 ¹¹	0.16	0.19	0.21	0.22	0.27	0.22	0.06	0.07	0.07	0.08	0.09	0.07	0.11	0.12	0.13	0.13	0.15	0.13
mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0024	0.0024	0.0025	0.0025	0.0025	0.0025	0.0012	0.0012	0.0012	0.0012	0.0013	0.0012
nickel (Ni)	mg/L	0.02 ³	-	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
silicon (Si)	mg/L	-	-	13.2	12.7	10.6	9.6	7.3	9.3	-	-	-	-	-	-	4.5	4.3	3.4	3.0	2.2	2.9
vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
zinc (Zn)	mg/L	-	0.0036 ⁶	0.98	0.94	0.79	0.71	0.54	0.69	0.35	0.33	0.27	0.24	0.18	0.23	0.35	0.33	0.27	0.24	0.18	0.23

1 World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2 Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3 Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

4 Based on long-term exposure.

5 Based on pH value less than 6.5. Baseline values for pH range from 6.1 to 6.2. The predicted pH value of the tailing seepage was 8.

6 Based on the dissolved form of this metal.

7 Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

8 Based on an alkalinity value of less than 60 mg/L.

9 Based on a dissolved saturation of at least 80%.

10 Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

11 Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

- 'No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-11 Water Quality Results From Basin B1

Water Quality Substance	Units	Guidelines		Dry Water Quality, Dry Flows						Wet Water Quality, Average Flows						Average Wet + Dry Water Quality, Average Flows					
		WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80
Conductivity	µS/cm	-	-	43	45	46	43	55	53	40	41	41	40	44	43	42	42	42	42	45	45
Total Alkalinity as CaCO ₃	mg/L	-	-	20	17	18	21	6	11	9	8	8	10	4	6	11	10	10	11	6	8
Nitrate (NO ₃)	mg/L	50	-	2.0	2.1	2.0	1.9	2.4	2.3	0.2	0.2	0.2	0.2	0.2	0.2	1.1	1.2	1.1	1.1	1.2	1.2
Nitrite (NO ₂)	mg/L	0.2 ^{3,4}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	3	3	3	4	2	2	2	2	2	2	1	1	2	2	2	2	1	1
Chloride (Cl)	mg/L	-	-	6.0	5.7	5.8	6.2	4.1	4.8	6.3	6.2	6.3	6.4	5.8	6.0	6.2	6.1	6.1	6.3	5.7	5.9
Magnesium (Mg)	mg/L	-	-	2	2	2	2	2	3	1	1	1	1	1	1	1	1	1	1	1	1
Sodium (Na)	mg/L	-	-	5.5	5.1	5.2	5.8	3.2	4.1	3.6	3.5	3.5	3.8	2.8	3.1	2.9	2.8	2.8	3.1	2.0	2.4
Sulphate (SO ₄)	mg/L	-	-	4	5	6	5	12	12	2	2	3	2	4	4	3	3	4	3	5	6
Aluminium (Al)	mg/L	-	0.01 ⁵	0.06	0.06	0.06	0.07	0.03	0.04	0.04	0.03	0.03	0.04	0.02	0.03	0.03	0.03	0.03	0.03	0.02	0.02
Arsenic (As)	mg/L	0.01 ³	0.02	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Barium (Ba)	mg/L	0.7	-	0.009	0.008	0.009	0.010	0.006	0.007	0.025	0.025	0.025	0.025	0.025	0.025	0.017	0.017	0.017	0.017	0.016	0.016
Chromium (Cr)	mg/L	0.05 ³	0.014 ^{6,7}	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
Cobalt (Co)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
Copper (Cu)	mg/L	2	0.00053 ^{6,8}	0.003	0.003	0.003	0.003	0.004	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.004	0.004
Iron (Fe)	mg/L	-	-	2.0	2.1	2.1	1.9	2.5	2.3	1.2	1.2	1.2	1.2	1.3	1.3	1.6	1.6	1.6	1.6	1.7	1.7
Lead (Pb)	mg/L	0.01	0.000475 ^{6,8,9}	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.051	0.051	0.050	0.053	0.052	0.026	0.026	0.026	0.026	0.028	0.027
Manganese (Mn)	mg/L	0.4 ¹⁰	0.37 ¹¹	0.16	0.18	0.22	0.18	0.35	0.35	0.06	0.06	0.07	0.07	0.11	0.11	0.11	0.12	0.13	0.12	0.17	0.17
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0001	0.0002	0.0002	0.0001	0.0001	0.0024	0.0025	0.0025	0.0024	0.0026	0.0025	0.0012	0.0012	0.0012	0.0012	0.0013	0.0013
Nickel (Ni)	mg/L	0.02 ³	-	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
Silicon (Si)	mg/L	-	-	12.2	10.6	11.0	13.6	2.0	6.0	-	-	-	-	-	-	4.2	3.5	3.6	4.8	0.5	1.8
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
Zinc (Zn)	mg/L	-	0.0036 ⁶	0.90	0.78	0.81	1.01	0.16	0.45	0.32	0.27	0.28	0.36	0.05	0.15	0.32	0.27	0.28	0.36	0.05	0.15

1 World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2 Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3 Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

4 Based on long-term exposure.

5 Based on pH value less than 6.5. Baseline values for pH range from 6.1 to 6.2. The predicted pH value of the tailing seepage was 8.

6 Based on the dissolved form of this metal.

7 Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

8 Based on an alkalinity value of less than 60 mg/L.

9 Based on a dissolved saturation of at least 80%.

10 Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

11 Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

- 'No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-12 Water Quality Results From Basin B2

Water Quality Substance	Units	Guidelines		Dry Water Quality, Dry Flows						Wet Water Quality, Average Flows						Average Wet + Dry Water Quality, Average Flows					
		WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80
conductivity	µS/cm	-	-	42	43	44	42	52	50	40	40	41	40	43	43	41	42	42	41	44	44
total alkalinity as CaCO ₃	mg/L	-	-	24	20	21	23	11	15	10	9	9	10	6	7	12	11	11	12	7	9
nitrate (NO ₃)	mg/L	50	-	1.9	2.0	2.0	1.9	2.3	2.1	0.2	0.2	0.2	0.2	0.2	0.2	1.1	1.1	1.1	1.1	1.2	1.2
nitrite (NO ₂)	mg/L	0.2 ^{3,4}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
calcium (Ca)	mg/L	-	-	4	4	4	4	2	3	2	2	2	2	1	1	2	2	2	2	1	2
chloride (Cl)	mg/L	-	-	6.6	6.1	6.1	6.4	4.8	5.3	6.5	6.3	6.4	6.5	6.0	6.1	6.4	6.2	6.2	6.3	5.8	6.0
magnesium (Mg)	mg/L	-	-	2	2	2	2	2	3	1	1	1	1	1	1	1	1	1	1	1	1
sodium (Na)	mg/L	-	-	6.2	5.6	5.6	6.0	4.1	4.7	3.9	3.7	3.7	3.8	3.1	3.3	3.2	2.9	3.0	3.1	2.3	2.6
sulphate (SO ₄)	mg/L	-	-	4	5	6	5	10	10	2	2	3	2	4	4	3	3	4	3	5	5
aluminium (Al)	mg/L	-	0.01 ⁵	0.07	0.06	0.06	0.07	0.04	0.05	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02
arsenic (As)	mg/L	0.01 ³	0.02	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
barium (Ba)	mg/L	0.7	-	0.010	0.009	0.009	0.010	0.007	0.008	0.025	0.025	0.025	0.025	0.025	0.025	0.017	0.017	0.017	0.017	0.016	0.016
chromium (Cr)	mg/L	0.05 ³	0.014 ^{6,7}	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
cobalt (Co)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
copper (Cu)	mg/L	2	0.00053 ^{6,8}	0.003	0.003	0.003	0.003	0.004	0.003	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.004	0.004
iron (Fe)	mg/L	-	-	1.9	2.0	2.0	1.9	2.3	2.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6	1.6	1.6	1.6	1.7	1.7
lead (Pb)	mg/L	0.01	0.000475 ^{6,8,9}	0.005	0.005	0.005	0.005	0.005	0.005	0.049	0.050	0.050	0.050	0.052	0.052	0.026	0.026	0.026	0.026	0.027	0.027
manganese (Mn)	mg/L	0.4 ¹⁰	0.37 ¹¹	0.16	0.17	0.19	0.17	0.31	0.30	0.06	0.06	0.07	0.06	0.10	0.10	0.11	0.12	0.12	0.12	0.15	0.16
mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0001	0.0001	0.0024	0.0024	0.0024	0.0024	0.0025	0.0025	0.0012	0.0012	0.0012	0.0012	0.0013	0.0012
mickel (Ni)	mg/L	0.02 ³	-	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
silicon (Si)	mg/L	-	-	15.4	12.8	13.0	14.8	5.9	8.8	-	-	-	-	-	-	5.3	4.2	4.3	5.0	1.7	2.6
vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
zinc (Zn)	mg/L	-	0.0036 ⁶	1.14	0.94	0.96	1.09	0.45	0.65	0.40	0.32	0.33	0.38	0.14	0.21	0.40	0.32	0.33	0.38	0.14	0.21

1 World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2 Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3 Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

4 Based on long-term exposure.

5 Based on pH value less than 6.5. Baseline values for pH range from 6.1 to 6.2. The predicted pH value of the tailing seepage was 8.

6 Based on the dissolved form of this metal.

7 Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

8 Based on an alkalinity value of less than 60 mg/L.

9 Based on a dissolved saturation of at least 80%.

10 Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

11 Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

- 'No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-13 Water Quality Results From Basin B3

Water Quality Substance	Units	Guidelines		Dry Water Quality, Dry Flows						Wet Water Quality, Average Flows						Average Wet + Dry Water Quality, Average Flows					
		WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80
Conductivity	µS/cm	-	-	44	44	44	44	44	44	40	40	40	40	40	40	42	42	42	42	42	42
Total Alkalinity as CaCO ₃	mg/L	-	-	18	18	18	18	18	18	8	8	8	8	8	8	10	10	10	10	10	10
Nitrate (NO ₃)	mg/L	50	-	2.0	2.0	2.0	2.0	2.0	2.0	0.2	0.2	0.2	0.2	0.2	0.2	1.1	1.1	1.1	1.1	1.1	1.1
Nitrite (NO ₂)	mg/L	0.2 ^{3,4}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	5.8	5.8	5.8	5.8	5.8	5.8	6.3	6.3	6.3	6.3	6.3	6.3	6.2	6.2	6.2	6.1	6.2	6.2
Magnesium (Mg)	mg/L	-	-	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1
Sodium (Na)	mg/L	-	-	5.2	5.2	5.2	5.2	5.2	5.2	3.6	3.6	3.6	3.6	3.6	3.6	2.8	2.8	2.8	2.8	2.8	2.8
Sulphate (SO ₄)	mg/L	-	-	4	4	4	4	4	4	2	2	2	2	2	2	3	3	3	3	3	3
Aluminium (Al)	mg/L	-	0.01 ⁵	0.06	0.06	0.06	0.06	0.06	0.06	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Arsenic (As)	mg/L	0.01 ³	0.02	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Barium (Ba)	mg/L	0.7	-	0.009	0.009	0.009	0.009	0.009	0.009	0.025	0.025	0.025	0.025	0.025	0.025	0.017	0.017	0.017	0.017	0.017	0.017
Chromium (Cr)	mg/L	0.05 ³	0.014 ^{6,7}	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
Cobalt (Co)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
Copper (Cu)	mg/L	2	0.00053 ^{6,8}	0.003	0.003	0.003	0.003	0.003	0.003	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.004	0.004
Iron (Fe)	mg/L	-	-	2.1	2.1	2.1	2.1	2.1	2.1	1.2	1.2	1.2	1.2	1.2	1.2	1.6	1.6	1.6	1.6	1.6	1.6
Lead (Pb)	mg/L	0.01	0.000475 ^{6,8,9}	0.005	0.005	0.005	0.005	0.005	0.005	0.051	0.051	0.051	0.051	0.051	0.051	0.026	0.026	0.026	0.026	0.026	0.026
Manganese (Mn)	mg/L	0.4 ¹⁰	0.37 ¹¹	0.16	0.16	0.16	0.16	0.16	0.16	0.06	0.06	0.06	0.06	0.06	0.06	0.11	0.11	0.11	0.11	0.11	0.11
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012
Nickel (Ni)	mg/L	0.02 ³	-	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
Silicon (Si)	mg/L	-	-	11.2	11.2	11.1	11.0	11.1	11.2	-	-	-	-	-	-	3.8	3.8	3.8	3.7	3.8	3.8
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
Zinc (Zn)	mg/L	-	0.0036 ⁶	0.83	0.83	0.82	0.82	0.82	0.83	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

4

Based on long-term exposure.

5

Based on pH value less than 6.5. Baseline values for pH range from 6.1 to 6.2. The predicted pH value of the tailing seepage was 8.

6

Based on the dissolved form of this metal.

7

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on a dissolved saturation of at least 80%.

10

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

11

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-14 Water Quality Results From Basin C1

Water Quality Substance	Units	Guidelines		Dry Water Quality, Dry Flows						Wet Water Quality, Average Flows						Average Wet + Dry Water Quality, Average Flows					
		WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80
Conductivity	µS/cm	-	-	42	42	44	47	54	48	40	40	41	41	44	42	41	41	42	43	45	43
Total Alkalinity as CaCO ₃	mg/L	-	-	23	23	17	10	8	13	10	10	8	5	5	6	12	12	9	7	6	8
Nitrate (NO ₃)	mg/L	50	-	1.9	1.9	2.1	2.3	2.4	2.2	0.2	0.2	0.2	0.2	0.2	0.2	1.1	1.1	1.2	1.2	1.2	1.2
Nitrite (NO ₂)	mg/L	0.2 ^{3,4}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	3	2	2	3	2	2	2	1	1	1	2	2	2	1	1	1
Chloride (Cl)	mg/L	-	-	6.4	6.4	5.6	4.6	4.4	5.1	6.5	6.5	6.2	5.9	5.9	6.0	6.3	6.3	6.1	5.8	5.7	5.9
Magnesium (Mg)	mg/L	-	-	2	2	2	1	2	2	1	1	1	1	1	1	1	1	1	1	1	1
Sodium (Na)	mg/L	-	-	6.0	6.0	5.0	3.8	3.5	4.4	3.8	3.8	3.5	3.0	2.9	3.2	3.1	3.1	2.7	2.3	2.2	2.5
Sulphate (SO ₄)	mg/L	-	-	4	4	4	4	12	7	2	2	2	2	4	3	3	3	3	3	5	4
Aluminium (Al)	mg/L	-	0.01 ⁵	0.07	0.07	0.06	0.04	0.03	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02
Arsenic (As)	mg/L	0.01 ³	0.02	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Barium (Ba)	mg/L	0.7	-	0.010	0.010	0.008	0.007	0.006	0.008	0.025	0.025	0.025	0.025	0.025	0.025	0.017	0.017	0.017	0.016	0.016	0.016
Chromium (Cr)	mg/L	0.05 ³	0.014 ^{6,7}	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
Cobalt (Co)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
Copper (Cu)	mg/L	2	0.00053 ^{6,8}	0.003	0.003	0.003	0.004	0.004	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.004	0.004
Iron (Fe)	mg/L	-	-	1.9	1.9	2.1	2.3	2.4	2.2	1.2	1.2	1.2	1.3	1.3	1.3	1.6	1.6	1.7	1.7	1.7	1.7
Lead (Pb)	mg/L	0.01	0.000475 ^{6,8,9}	0.005	0.005	0.005	0.005	0.005	0.005	0.050	0.050	0.051	0.053	0.053	0.052	0.026	0.026	0.026	0.027	0.027	0.027
Manganese (Mn)	mg/L	0.4 ¹⁰	0.37 ¹¹	0.16	0.16	0.16	0.17	0.35	0.22	0.06	0.06	0.06	0.05	0.11	0.07	0.11	0.11	0.11	0.11	0.16	0.13
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0024	0.0024	0.0025	0.0025	0.0026	0.0025	0.0012	0.0012	0.0012	0.0013	0.0013	0.0013
Nickel (Ni)	mg/L	0.02 ³	-	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
Silicon (Si)	mg/L	-	-	14.8	14.8	10.4	4.9	3.6	7.5	-	-	-	-	-	-	5.0	5.0	3.3	1.3	0.9	2.2
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
Zinc (Zn)	mg/L	-	0.0036 ⁶	1.09	1.09	0.77	0.38	0.28	0.56	0.38	0.38	0.26	0.12	0.09	0.18	0.38	0.38	0.26	0.12	0.09	0.18

- 1
- World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.
- 2
- Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.
- 3
- Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.
- 4
- Based on long-term exposure.
- 5
- Based on pH value less than 6.5. Baseline values for pH range from 6.1 to 6.2. The predicted pH value of the tailing seepage was 8.
- 6
- Based on the dissolved form of this metal.
- 7
- Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.
- 8
- Based on an alkalinity value of less than 60 mg/L.
- 9
- Based on a dissolved saturation of at least 80%.
- 10
- Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.
- 11
- Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.
-
- No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-15 Water Quality Results From Basin C2

Water Quality Substance	Units	Guidelines		Dry Water Quality, Dry Flows						Wet Water Quality, Average Flows						Average Wet + Dry Water Quality, Average Flows					
		WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80
Conductivity	µS/cm	-	-	42	42	43	45	51	46	40	40	40	41	43	41	41	41	42	42	44	43
Total Alkalinity as CaCO ₃	mg/L	-	-	24	24	20	14	12	16	10	10	9	7	6	7	12	12	11	8	8	9
Nitrate (NO ₃)	mg/L	50	-	1.9	1.9	2.0	2.2	2.2	2.1	0.2	0.2	0.2	0.2	0.2	0.2	1.1	1.1	1.1	1.2	1.2	1.2
Nitrite (NO ₂)	mg/L	0.2 ^{3,4}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	2	3	3	2	2	2	1	1	1	2	2	2	1	1	2
Chloride (Cl)	mg/L	-	-	6.6	6.6	6.1	5.2	5.0	5.5	6.5	6.5	6.3	6.1	6.0	6.2	6.4	6.4	6.2	5.9	5.9	6.0
Magnesium (Mg)	mg/L	-	-	2	2	2	1	3	2	1	1	1	1	1	1	1	1	1	1	1	1
Sodium (Na)	mg/L	-	-	6.2	6.2	5.6	4.5	4.2	4.9	3.9	3.9	3.7	3.2	3.2	3.4	3.2	3.2	2.9	2.5	2.4	2.6
Sulphate (SO ₄)	mg/L	-	-	4	4	4	4	10	6	2	2	2	2	4	3	3	3	3	3	5	4
Aluminium (Al)	mg/L	-	0.01 ⁵	0.07	0.07	0.06	0.05	0.04	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.03
Arsenic (As)	mg/L	0.01 ³	0.02	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Barium (Ba)	mg/L	0.7	-	0.010	0.010	0.009	0.008	0.007	0.008	0.025	0.025	0.025	0.025	0.025	0.025	0.017	0.017	0.017	0.016	0.016	0.016
Chromium (Cr)	mg/L	0.05 ³	0.014 ^{6,7}	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
Cobalt (Co)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
Copper (Cu)	mg/L	2	0.00053 ^{6,8}	0.003	0.003	0.003	0.004	0.004	0.003	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.004	0.004
Iron (Fe)	mg/L	-	-	1.9	1.9	2.0	2.2	2.3	2.1	1.2	1.2	1.2	1.3	1.3	1.3	1.6	1.6	1.6	1.7	1.7	1.7
Lead (Pb)	mg/L	0.01	0.000475 ^{6,8,9}	0.005	0.005	0.005	0.005	0.005	0.005	0.049	0.049	0.050	0.052	0.052	0.051	0.026	0.026	0.026	0.027	0.027	0.027
Manganese (Mn)	mg/L	0.4 ¹⁰	0.37 ¹¹	0.16	0.16	0.16	0.17	0.30	0.21	0.06	0.06	0.06	0.05	0.10	0.07	0.11	0.11	0.11	0.11	0.15	0.13
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0001	0.0001	0.0001	0.0024	0.0024	0.0024	0.0025	0.0025	0.0025	0.0012	0.0012	0.0012	0.0013	0.0013	0.0012
Nickel (Ni)	mg/L	0.02 ³	-	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
Silicon (Si)	mg/L	-	-	15.4	15.4	12.8	7.8	6.7	9.7	-	-	-	-	-	-	5.3	5.3	4.2	2.3	1.9	3.0
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
Zinc (Zn)	mg/L	-	0.0036 ⁶	1.13	1.13	0.95	0.58	0.51	0.72	0.40	0.40	0.32	0.19	0.16	0.23	0.40	0.40	0.32	0.19	0.16	0.23

1

World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2

Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3

Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

4

Based on long-term exposure.

5

Based on pH value less than 6.5. Baseline values for pH range from 6.1 to 6.2. The predicted pH value of the tailing seepage was 8.

6

Based on the dissolved form of this metal.

7

Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

8

Based on an alkalinity value of less than 60 mg/L.

9

Based on a dissolved saturation of at least 80%.

10

Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

11

Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

-

No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-16 Water Quality Results From Basin C3

Water Quality Substance	Units	Guidelines		Dry Water Quality, Dry Flows						Wet Water Quality, Average Flows						Average Wet + Dry Water Quality, Average Flows					
		WHO Drinking Water ¹	South African Aquatic Ecosystems ²	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80	Baseline	Year 14	Year 20	Year 27	Post-closure 15	Post-closure 80
Conductivity	µS/cm	-	-	42	42	43	45	49	45	40	40	40	41	42	41	41	41	41	42	44	42
Total Alkalinity as CaCO ₃	mg/L	-	-	24	24	21	16	15	18	10	10	9	7	7	8	12	12	11	9	9	10
Nitrate (NO ₃)	mg/L	50	-	1.9	1.9	1.9	2.1	2.1	2.1	0.2	0.2	0.2	0.2	0.2	0.2	1.1	1.1	1.1	1.2	1.2	1.2
Nitrite (NO ₂)	mg/L	0.2 ^{3,4}	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Calcium (Ca)	mg/L	-	-	4	4	4	3	3	3	2	2	2	1	1	2	2	2	2	2	2	2
Chloride (Cl)	mg/L	-	-	6.6	6.6	6.2	5.5	5.3	5.7	6.5	6.5	6.4	6.1	6.1	6.2	6.4	6.4	6.3	6.0	6.0	6.1
Magnesium (Mg)	mg/L	-	-	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1
Sodium (Na)	mg/L	-	-	6.2	6.2	5.8	4.8	4.6	5.1	3.9	3.9	3.7	3.4	3.3	3.5	3.2	3.2	3.0	2.6	2.5	2.7
Sulphate (SO ₄)	mg/L	-	-	4	4	4	4	9	6	2	2	2	2	3	2	3	3	3	3	5	4
Aluminium (Al)	mg/L	-	0.01 ⁵	0.07	0.07	0.07	0.05	0.05	0.06	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.03
Arsenic (As)	mg/L	0.01 ³	0.02	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.002	0.002
Barium (Ba)	mg/L	0.7	-	0.010	0.010	0.009	0.008	0.008	0.009	0.025	0.025	0.025	0.025	0.025	0.025	0.017	0.017	0.017	0.016	0.016	0.017
Chromium (Cr)	mg/L	0.05 ³	0.014 ^{6,7}	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
Cobalt (Co)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
Copper (Cu)	mg/L	2	0.00053 ^{6,8}	0.003	0.003	0.003	0.003	0.003	0.003	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.004	0.004
Iron (Fe)	mg/L	-	-	1.9	1.9	1.9	2.1	2.2	2.1	1.2	1.2	1.2	1.3	1.3	1.2	1.6	1.6	1.6	1.7	1.7	1.6
Lead (Pb)	mg/L	0.01	0.000475 ^{6,8,9}	0.005	0.005	0.005	0.005	0.005	0.005	0.049	0.049	0.050	0.051	0.052	0.051	0.026	0.026	0.026	0.027	0.027	0.026
Manganese (Mn)	mg/L	0.4 ¹⁰	0.37 ¹¹	0.16	0.16	0.16	0.16	0.27	0.20	0.06	0.06	0.06	0.06	0.09	0.07	0.11	0.11	0.11	0.11	0.15	0.12
Mercury (Hg)	mg/L	0.001	0.00008	0.0002	0.0002	0.0002	0.0001	0.0001	0.0002	0.0024	0.0024	0.0024	0.0025	0.0025	0.0025	0.0012	0.0012	0.0012	0.0012	0.0013	0.0012
Nickel (Ni)	mg/L	0.02 ³	-	0.002	0.002	0.002	0.002	0.002	0.002	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
Silicon (Si)	mg/L	-	-	15.4	15.4	13.6	9.4	8.6	10.8	-	-	-	-	-	-	5.3	5.3	4.5	2.9	2.6	3.4
Vanadium (V)	mg/L	-	-	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003	0.003	0.003	0.003	0.003
Zinc (Zn)	mg/L	-	0.0036 ⁶	1.13	1.13	1.00	0.70	0.64	0.80	0.40	0.40	0.34	0.23	0.21	0.27	0.40	0.40	0.34	0.23	0.21	0.27

1World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization.

2Chronic Effect Values (CEV) from South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.

3Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.

4Based on long-term exposure.

5Based on pH value less than 6.5. Baseline values for pH range from 6.1 to 6.2. The predicted pH value of the tailing seepage was 8.

6Based on the dissolved form of this metal.

7Based on hexavalent form chromium, the trivalent form is 0.024 mg/L.

8Based on an alkalinity value of less than 60 mg/L.

9Based on a dissolved saturation of at least 80%.

10Concentrations of the substance at or below the health based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints.

11Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

-No guideline or predicted value (baseline data from the wet season were not available for some water quality substances).

Table 9.2-17 Baseline and Maximum Predicted Sediment Quality Results From the Tailings Facility Area

Parameters	Units	Baseline Sediment Concentration	Operations		Post-closure		Canadian Quality	
			Maximum Sediment Concentration	Maximum Increase from Baseline	Maximum Sediment Concentration	Maximum Increase from Baseline	ISQG ²	PEL ³
Aluminum	mg/kg	52025	52025	0.147	52025	0		
Arsenic	µS/cm	0.038	0.039	0.0005	0.038	0	5.9	17
Total Alkalinity as CaCO ₃	mg/kg	4.70	4.71	0.01	4.70	0.002		
Nitrate (NO ₃)	mg/kg	-	-	0.009	-	0.009	37.3	90
Nitrite (NO ₂)	mg/kg	8.2	8.2	0.006	8.2	0.01		
Copper	mg/kg	25.8	25.8	0.02	25.8	0.02	35.7	197
Lead	mg/kg	0.860	0.965	0.11	0.977	0.12	35	91.3
Manganese	mg/kg	125.8	128.7	3.0	128.5	2.7		
Mercury	mg/kg	0.042	0.046	0.005	0.047	0.005	0.17	0.486
Sulphate (SO ₄)	mg/kg	38.5	38.5	0.006	38.5	0.007		
Vanadium	mg/kg	147	147	0.006	147	0.007		
Zinc	mg/kg	0.7	3	2.3	0.7	0	123	315
Iron	mg/kg	27950	27956	6.4	27957	7.2		

1 Canadian Sediment Quality Guidelines (updated February 2002).

2 ISQG = interim sediment quality guideline.

3 PEL = probable effects level.

- absolute concentrations are not presented because baseline chromium values of sediment concentrations were not available.

Table 9.2-18 Bioassay Reports



48hr *Daphnia magna* Bioassay Report

(Acute Aquatic Toxicity Test)

Project : A531167-886279

Client Name :	DynaTec Corporation
Location :	Fort Saskatchewan, AB

Sample Data :

Sample Description :	Tailings Supernatant		
Visual Description:	Clear liquid		
Sampling Location :	n/g		
Sampling Method :	Grab		
Volume Obtained :	1 L		
Sampled By :	n/g		
Sample Date :	05 08 03	Time :	n/g
Date Received :	05 08 12	Time :	0800
Bioassay Date :	05 08 12	Time :	1520
Report Date :	05 08 17		
Deviations from Method :	none		

Bioassay Results :

LC50 @ 48 Hours :	31.1%
Method :	Non-Linear Interpolation
95 % Confidence Interval :	25.0<31.1<50.0

Legend: LC50/EC50 indicates concentration of sample, in percent, which kills or affects 50% of test organisms.
--

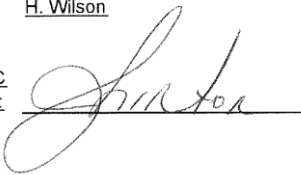
Results of Sodium Chloride Reference Bioassay :

LC50 @ 48 Hours :	5839 mg/L
95 % Confidence Interval :	5500<5839<6500
Method :	Non-Linear Interpolation
95 % Confidence Interval :	5410<5830<6251
Method :	Schewhart Warning Limts
Historical Mean \pm 2SD :	5830 \pm 420
Date of Reference Bioassay :	05 08 03

Data

Verified By: H. Wilson

Data & QA/QC

Reviewed By: 

Edmonton: 9331-48 Street T6B 2R4 Tel:(780) 468-3500 Fax:(780) 466-3332



48hr *Daphnia magna* Bioassay Report

Project : A531167-886279

Detailed Test Information :

Type of Bioassay :	48 hour static bioassay
Test Species :	<i>Daphnia magna</i>
Test Protocol :	Environment Canada EPS 1/RM/14 (December 2000 ed.)
Test Endpoint:	Mortality and/or Immobility
% Mortality in Culture 7 days Prior to Testing :	3.1%
Age of Test Animals :	Neonates (young), less than 24 hours old
Time, in Days, to First Brood :	9
Average Number of Neonates per Brood :	32
Source of Test Species :	In house culture initiated through Environment Canada <i>Daphnia magna</i>
Date Animals Obtained :	May 1991
Source of Culturing and Dilution Water :	Reconstituted water
Size of Test Container :	200 mL
Material of Test Container :	Polyethylene beaker
Volume of Test Solution per Container :	160 mL
Standard Concentrations of Test Material :	0, 6.25, 12.5, 25, 50, 100%
Number of Neonates per Container :	10
Volume of Solution per Daphnid :	16 mL
Hardness Adjustment :	None (Checked with Hach Kit for Total Hardness, 20-400mg/L)

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48hr *Daphnia magna* Bioassay Report

Project : A531167-886279

Setup	Effluent Properties Prior To Initial Setup:	Temperature °C	pH @ 20°C	EC µS cm-1	Dissolved Oxygen mg/L
Analyst: JL	Preaeration Time (at rate of 50 mL / min / L) :	19.1	7.2	8507	9.5
		0 min			

Time	Description	Concentration (% by Volume)					
		0	6.25	12.5	25	50	100

Start	Temperature °C	21.1	21.0	20.9	20.9	20.7	20.4
	pH @ 20°C	8.4	8.3	8.1	8.0	7.7	7.5
	EC µS cm-1	631	1266	2080	3175	5088	8447
	Dissolved Oxygen mg/L	8.8	8.8	8.7	8.8	8.1	6.4
	Hardness mg/L CaCO3	210					120
Analyst: JL							
1 Hour	Number Dead						
Analyst:	Atypical/Stressed Behaviour						
4 Hours	Number Dead						
Analyst:	Atypical/Stressed Behaviour						
24 Hours	Number Dead	0	0	0	2	8	10
Analyst: JL	Atypical/Stressed Behaviour	0	0	0	0	21	n/a
48 Hours	Temperature °C	21.2	21.4	21.8	21.6	21.7	21.7
	pH @ 20°C	8.5	8.4	8.3	8.2	8.0	7.9
	EC µS cm-1	642	1250	2041	3133	5024	8361
	Dissolved Oxygen mg/L	8.3	8.8	8.6	8.6	8.2	6.7
	Number Dead	0	0	0	2	10	10
Analyst: JL	Atypical/Stressed Behaviour	0	0	0	0	n/a	n/a

Observation Codes: I: Immobile F: Floating

General Comments:



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1 of 3

96hr Rainbow Trout Bioassay Report

(Acute Aquatic Toxicity Test)

Project : A531167-886279

Client Name :	DynaTec Corporation
Location :	Fort Saskatchewan, AB

Sample Data :

Sample Description :	Tailings Supernatant		
Sampling Location :	n/g		
Sampling Method :	Grab		
Volume Obtained :	60 L		
Sampled By :	n/g		
Sample Date :	05 08 03	Time :	n/g
Date Received :	05 08 12	Time :	0800
Bioassay Date :	05 08 12	Time :	1635
Report Date :	05 08 17		
Deviations from Method :	none		

Bioassay Results :

LC50 @ 96 Hours :	>100%
Method :	n/a
95 % Confidence Interval :	n/a
EC50 @ 96 Hours :	>100%
Method :	n/a
95 % Confidence Interval :	n/a

Legend:
LC50/EC50 indicates concentration
of sample, in percent, which kills
or affects 50% test organisms.

Results of Phenol Reference Bioassay :

LC50 @ 96 Hours :	13.7 mg/L
95 % Confidence Interval :	12.2<13.7<15.4
Method :	Probit
95 % Confidence Interval :	7.00<12.0<16.9
Method :	Schewhart Warning Limits
Historical Mean \pm 2SD :	12.0 \pm 4.98
Date of Reference Bioassay :	05 07 12

Data

Verified By: H. Wilson

Data & QA/QC

Reviewed By: 

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96hr *Rainbow Trout* Bioassay Report

Test Information :

Type of Bioassay :	96 Hour Multiple Dilution Static Bioassay		
Test Species :	<i>Oncorhynchus mykiss</i> (Rainbow Trout)		
Test Protocol :	Environment Canada EPS 1/RM/13 (Dec.2000 ed.)		
Source of Test Species :	Sun Valley Trout Farms, Mission, BC.		
Culture Lot # :	Sv0629-3		
Mean (± 1 SD) & Range Fork Length of Fish :	3.6 \pm 0.1 cm	3.4 - 3.8	n= 10
Mean (± 1 SD) & Range Weight of Fish :	0.56 \pm 0.06 g	0.45 - 0.67	
Cummulative Mortality of Fish Lot in the 7 Days Prior to Test :	0.0%		
Source of Holding Water :	Ammonia Free, Dechlorinated City of Edmonton Tap Water		
Size of Test Container :	38 L		
Material of Test Container :	Disposable Plastic Liner in Glass Tank		
Volume of Test Solution in Each Test Vessel :	20 L		
Depth of Test Material in Each Test Vessel :	≥ 15 cm		
Concentrations of Test Material :	0, 20, 40, 60, 80, 100%		
Number of Fish per Test Vessel :	10		
Loading Density :	0.28 g/L		
Method of Aeration :	Carbon Filtered, Compressed Air Through Air-stone		
Aeration Rate during test :	6.5 \pm 1.0 mL/min./L		

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3 of 3

96hr Rainbow Trout Bioassay Report

Time	Description	Concentration (% by Volume)					
		0	20	40	60	80	100
Setup	Sample Properties Prior To Initial Setup:	19.1	7.2	8507	9.5		
	Analyst: DT	Preparation Time (at rate of 6.5 ± 1.0 mL / min / L) : 60 min					
Start	Temperature (°C)	15.8	15.4	15.4	15.1	14.3	15.1
	pH	8.0	7.9	7.8	7.7	7.6	7.4
Analyst: DT	EC (µS cm ⁻¹)	321	2519	3873	5608	6954	8487
	Dissolved Oxygen (mg/L)	9.4	9.3	8.6	8.2	7.9	7.3
1/4 Hour	Number Dead						
	Atypical/Stressed Behaviour						
Analyst:	1/2 Hour						
	Number Dead						
Analyst:	1 Hour						
	Number Dead						
Analyst:	2 Hours						
	Number Dead						
Analyst:	4 Hours						
	Number Dead						
24 Hours	Temperature (°C)	15.1	14.8	14.8	14.9	14.9	15.1
	pH	8.0	8.0	8.0	8.0	7.9	7.7
Analyst: DT	EC (µS cm ⁻¹)	321	518	3874	5613	6961	8489
	Dissolved Oxygen (mg/L)	9.5	9.7	9.6	9.4	9.4	9.3
Analyst: DT	Number Dead	0	0	0	0	0	0
	Atypical/Stressed Behaviour	0	0	0	0	0	0
48 Hours	Temperature (°C)	15.0	14.7	14.8	14.9	15.1	15.2
	pH	7.9	7.8	7.6	7.6	7.7	7.7
Analyst: DT	EC (µS cm ⁻¹)	322	2524	2874	5617	6921	8490
	Dissolved Oxygen (mg/L)	8.9	8.5	8.8	8.8	9.8	9.6
Analyst: DT	Number Dead	0	0	0	0	0	0
	Atypical/Stressed Behaviour	0	0	0	0	0	0
72 Hours	Temperature (°C)	14.5	14.4	14.4	14.6	14.7	14.9
	pH	8.1	8.1	8.0	7.8	7.8	7.7
Analyst: DT	EC (µS cm ⁻¹)	322	2534	3880	5586	6981	8516
	Dissolved Oxygen (mg/L)	9.4	8.7	9.0	9.0	9.4	9.4
Analyst: DT	Number Dead	0	0	0	0	0	1
	Atypical/Stressed Behaviour	0	0	0	0	0	0
96 Hours	Temperature (°C)	15.3	14.6	14.4	14.5	14.6	14.8
	pH	7.9	7.9	7.9	7.8	7.8	7.8
Analyst: JL	EC (µS cm ⁻¹)	319	2508	3865	5642	6986	8564
	Dissolved Oxygen (mg/L)	9.5	9.5	9.4	9.3	9.2	9.2
Analyst: JL	Number Dead	0	0	0	0	0	1
	Atypical/Stressed Behaviour	0	0	0	0	0	0

Stress Codes: P: dark pigmentation U: light pigmentation L: lethargic H: hyperactive M: inhibited movement G: pronounced opercular movement S: extreme toxic shock D: disoriented

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2 REFERENCES

Groundwater Consulting Services (PTY) Ltd. 2005. Ambatovy Project - Tailings Disposal Facility Feasibility Design, Hydrogeological Study for Knight Piésold Ltd Report 04.01.040 3 April 2005.

Penttinen, Stan Dynatec (July 2005) Personal Communication of Effluent Quality (July 21st Revised).

VOLUME I: PHYSICAL APPENDICES

APPENDIX 10.1

ATTACHMENT 1

OCEANOGRAPHY AND MARINE BIOLOGY

HARBOUR EXPANSION

Submitted to:

Dynatec Corporation

MARINE SPECIALIST STUDIES

AMABATOVY PROJECT, MADAGASCAR: HARBOUR EXPANSION

Prepared by:



Coastal & Environmental Services
P.O. Box 934
Grahamstown
6140

Prepared for:

Dynatec Corporation
8301 – 113 Street
Fort Saskatchewan, Alberta
Canada, T8L 4K7

December 2005

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CHAPTER 1 INTRODUCTION

1.1 INTRODUCTION

Coastal & Environmental Services (CES) was appointed by Dynatec Corporation (Metallurgical Technologies Division) to conduct the marine specialist studies for the proposed Tamatave Harbour expansion in Madagascar. This followed on from the pre-feasibility study conducted by CES in 2004. These studies will be integrated in the full Environmental Impact Assessment Report being produced by Golder Associates Ltd, Canada.

The town and port of Tamatave is located at approximately 18° 09.00 S; 49° 25.00 E on the NE coast of Madagascar in the Toamasina Province. The proposed port expansion and marine outfall forms part of the Ambatovy Laterite Project also within the region. The marine outfall is dealt with in a separate report.

The information on which this study is based was obtained in two separate site visits occurring in June 2004 and August 2005. Both involved week long site visits, which included interviews with the proponent and various representatives of the Tamatave Port Authorities.

The port is currently in close proximity to a number of sensitive areas. The sensitive areas could best be summarized in two categories namely the natural and the social environment. This report will specifically address any potential impacts on the marine and coastal environments. Socio-economic impacts, which could include the increase in noise or visual intrusion, were also assessed.

1.2 PROJECT DESCRIPTION

The Tamatave Harbour is the main port of Madagascar, with Tamatave (Toamasina) being the economic capital of the country (Figure 1.1). The present port operates in three sections namely Moles A, B and C and is protected from large cyclonic waves by a breakwater. The port has berth occupancy in excess of 66%, and requires expansion to accommodate the raw material and product movement for the Ambatovy Project. The three moles currently in use include Mole A for small vessels, Mole B for fuel and oil, while Mole C operates as a deepwater cargo handling berth. The backwater area behind Mole A is used primarily for the commercial fishing fleet, port's tugs and pilot vessels.

Shipping traffic has increased in relation to improved socio-economic development policies. This has led to the steady increase in traffic within the last two financial years (Toamasina Port Annual Report, 2005). With the anticipated traffic as a result of the Ambatovy Laterite Project, the Port requires that berth capacity be increased and the infrastructure be improved/reinstated. The existing ship unloading facilities at the port have insufficient capacity

to handle the import of bulk raw materials (coal, sulphur and limestone) that are required for the project. The project will require the extension of Mole B using an open piling structure (Figure 1.2 & Photo Plate 1 & 2). The port will also be used to import fuels, anhydrous ammonia, miscellaneous reagents and spare parts for the project and to export nickel/cobalt sulphides. The extension of Mole B will also provide greater water depth for vessels with deeper draughts to handle the 60 000 ton sulphur

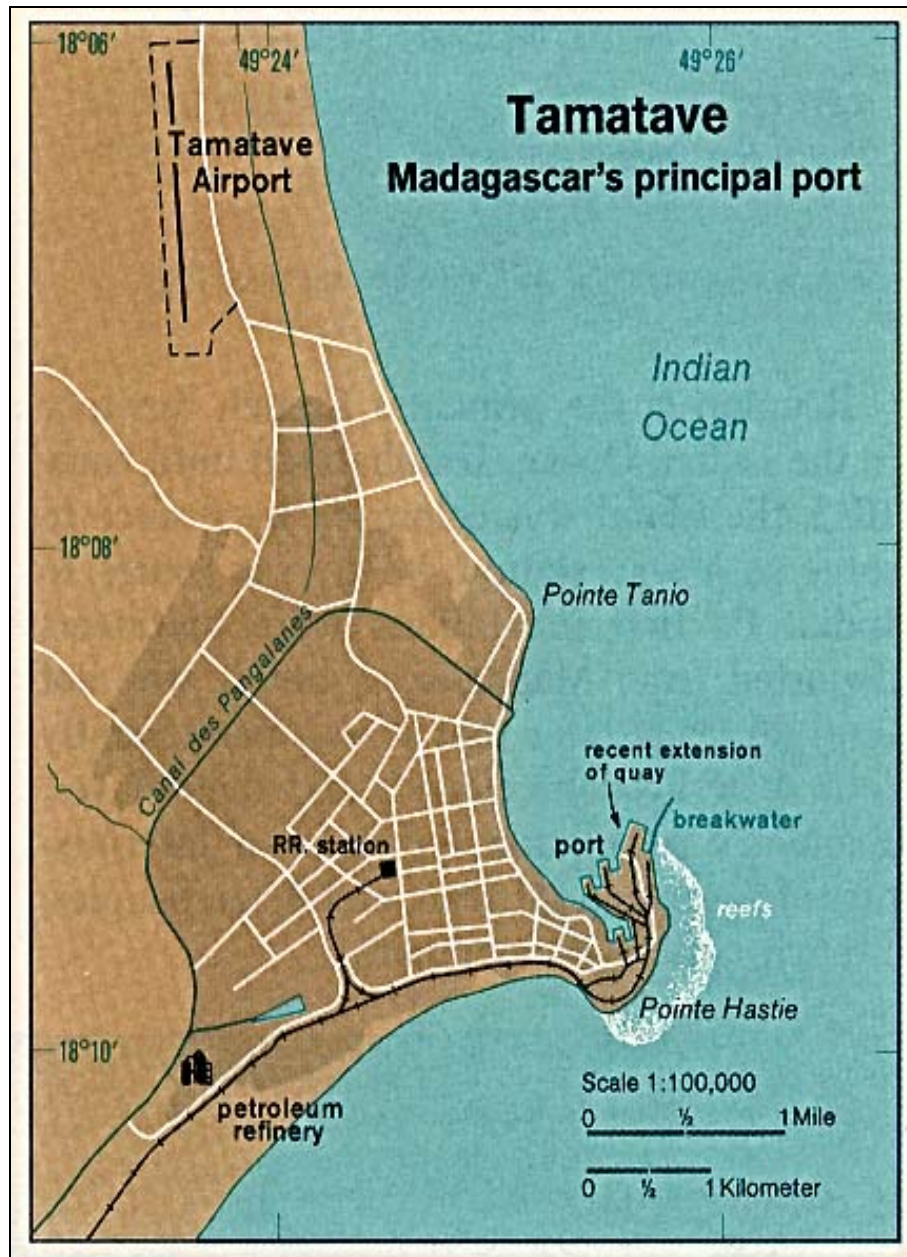


Figure 1.1: Study area locality indicating the Port expansion area.

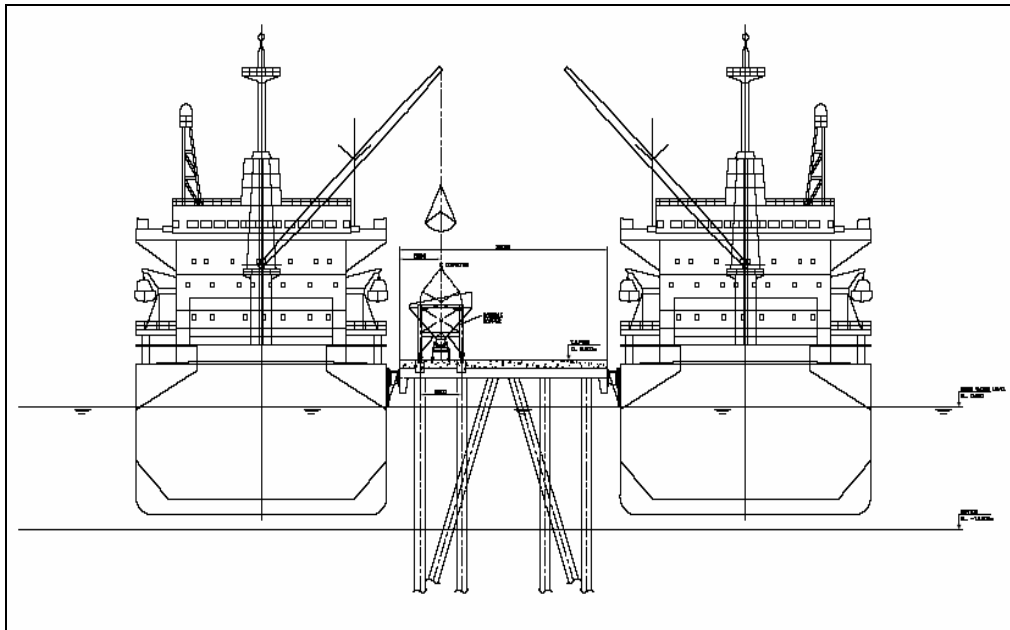


Figure 1.2: Diagrammatic representation of the quay structure indicating the layout of the open piling. Taken from Sandwell Drawing No: 142899-0007SK (Revision P1).



Photo Plate 1.1: The end of the current Mole B, which will be extended in the proposed project.



Photo Plate 1.2: Aerial view of the Port of Toamasina.

No additional warehouses are required, but stockpiles will be established and sized so that the expected shipment size may be unloaded;

- Sulphur 60 000 tons
- Coal 24 000 tons
- Limestone 15 000 tons

Construction Phase

Mole B will be extended using an open piling quay structure. No dredging or seabed preparation is required. It will be done from a piling barge or the existing quay. Once the piles have been driven, pre-cast beams will be placed on the pile caps or on temporary supports, then fixed into position with concrete.

The conveyors required for bulk transport, will be on raised gantries supported on steel structures with cast concrete foundations. The erection of the foundations will be done on site, while the steelwork will be assembled offsite and be erected in place so as to minimise the impact on the port operations. All painting will be done off-site except the final coat, which will be applied by brush.

Un-surfaced roads will be sprayed with water, as necessary to ensure dust is kept to acceptable limits.

Substantial topsoil stockpiles are not expected. Construction waste will be disposed of in an environmentally acceptable manner at a formal disposal site. Noise from the construction is not expected to be substantially different from the current harbour operating activities.

Operational Phase

Sulphur, Coal and Limestone will be unloaded using automated grab. This is programmed to perform the unloading with the minimum of personnel involvement so as to minimise spillage and operator error.

Conveyer gantries will be enclosed so that any spillage from the belts is contained in the gantry from where it is recovered, if and when necessary. The volume is not expected to be significant. The conveyor transfer houses (where spillage is most likely) will be supplied with vacuum cleaning piping, so a mobile vacuum cleaner truck can be used to remove the spill.

The stockpiles will be on concrete slabs with a means to trap any runoff, which will be treated as necessary, before release.

Petroleum products and anhydrous ammonia will be unloaded in pipelines. Spills will be treated with the appropriate absorption materials, which will be made available in mobile containers.

Emergency Response Plans

Appropriate fire fighting facilities will be made available at the harbour. A response team will have trained in the control of fires and spills.

Dust Control

The major cause of dust will be the transfer points of the conveyer system. Each transfer house will be fitted with a dust collection system consisting of fans and dust collection bag filters. The atmosphere inside the house and the exhaust of the fans will be specified to meet World Bank standards. The bag filters will be of the reverse flow cleaning type and the dust trapped will be deposited on the belts and sent to the appropriate stockpile. The changing from one product to another will be done via a programmable logic controller (PLC) to ensure that the appropriate train is selected for a particular product to avoid inadvertent mixing and to ensure that the dust from each batch is cleaned from the system before the next product is conveyed. Stockpiles will be open, but will be provided with water sprays to control dust. Covering stockpiles was not considered economically viable or necessary.

1.3 RATIONALE OF STUDY

During the construction and operation of the port there are a number of project actions that could significantly impact on the marine, nearshore and coastal environments. As detailed in Section 1.2 the project description, the principal project activities include:

- The construction of an open pile quay structure.
- The increase in shipping traffic with round the clock (24 hour a day) handling;
- Refuelling and general servicing of vessels.
- Unloading and loading of various cargoes, which are potentially hazardous.
- The possible intrusion on the visual sense of place, by larger ships expected closer to shore and the additional lighting at night.
- Increase in expected noise levels during construction and operation phases.

The operational activities associated with the Ambatovy have been engineered in such a way using contained handling systems, which if properly maintained will have a limited impact of the marine and social (Health and safety) environments.

This study provides an assessment of the proposed development by environmental and marine engineering specialists in consultation with government representatives and a limited number of IAPs who have raised specific issues. This study deals only with issues affecting the marine environment and coastal habitats. Issues were regarded as either a risk (negative impact) or an opportunity (positive impact). Based on these assessments, recommendations were made to Dynatec regarding the options available to them, and the environmental risks associated with each of them. An example of this was the exclusion of expanding Moles A and C, due to the inherent environmental risk and engineering constraints. Thus this study focuses on the third alternative the expansion of Mole B. The risk assessment of the three alternative sites is presented in Volume F, Section 1.

1.4 LIMITATIONS

- Specialist studies based on preliminary designs.
- Numerous activities in the region are currently impacting on the environment and the possible future impacts from the proposed operations may be difficult to discern.

Terms of Reference

CES were approached by Dynatec Corporation to conduct a study on the possible effects the port expansion activities and operations may have on the marine environment.

The specialist studies associated with the harbour extension assessed potential impacts related to bio-physical (aquatic) and socio-economic (noise, visual, employment, etc.) aspects, and included a preliminary risk overview to determine safety and hazards as they pertain to the vessels and products (imported and exported) linked to the Ambatovy Nickel Project.

The objectives (terms of reference; TOR) for this specialist study were to:

- Provide input into impact and mitigation statements regarding the construction and operation phases linked to the harbour expansion.
- Provide an environmental risk report on the project (Fatal flaw analysis).
- Provide a preliminary hazardous chemicals risk overview, relating to the substances being imported and exported as part of this project.
- Provide a broad description of the potential visual and noise impacts.

1.5 REPORT WRITING ROLES

AQUATERRE provided a summary document on:

- All existing harbour data as it pertains to bathymetry and sediments (composition and levels of pollutants);
- Port water quality data (Inclusive of the sections of the Pangalanes Canal close to the harbour),
- Sources of land based contamination (e.g. stormwater, sewerage, domestic waste, animal waste etc.);
- Oceanography, harbour traffic (number of ships/year, type of cargo and its origins/destination); and
- A brief assessment of the economic importance of the Port (contribution to National economy and importance to local region, i.e. employment and spin offs for local business in Toamasina).

CES assessed the following with regards:

- The current status quo harbour activities and associated impacts:
- The qualitative evaluation of the (likelihood and severity) associated impacts of the proposed harbour extension and the activities related to the Ambatovy Nickel Project.
- Provide an overview of the mitigation measures for all rated impacts.

Interaction with local authorities as required, but no detailed public participation will be undertaken

1.6 STRUCTURE OF THIS STUDY

Chapter 1 provides a brief introduction to the study, a description of the proposed activities, the rationale behind the proposed development, the terms of reference, the structure of the report and the project team members.

Chapter 2 details the approach, methodology and evaluation criteria used in the baseline study.

Chapter 3 provides an environmental description of the area, and includes aspects of the port importance, marine environment, coastal habitat, together with the noise and visual assessment of the adjacent area.

Chapter 4 provides references.

The impact assessment, and methods used in the assessment are provided in Volume F, Section 3.3.

1.7 STUDY TEAM

1.7.1 PRE-FEASIBILITY PHASE TEAM

The pre-feasibility study team was made up of Dr. Angus Paterson from CES, Dr. Aidan Wood from Gleneagles Environmental Consulting (GEC), Prof. Michael Schleyer of the Oceanographic Research Institute (ORI), Mr. Anton Holtzhausen and Mr. Jo Dresner from PRDW, Ms. Naomi Richardson from Rhodes University and Mr. Richard Andrianasolonanahary from Dynatec.

Dr. Paterson was the project leader, reviewer and the primary liaison between CES and Dynatec. In addition he provided logistical and administrative backup.

Dr. Wood was the project manager and was responsible for the coordination of the research team and the production of the pre-feasibility report. He provided specialist input pertaining to aspects of the marine ecology of the site and consulted with authorities and other interest groups affected by the proposed activities.

Ms. Naomi Richardson was the translator and facilitated many of the interviews and business transactions that were conducted.

Mr. Andrianasolonanahary, was based in Tamatave and facilitated interviews with the Port Authorities, Fisheries representatives and the local population.

1.7.2 ENVIRONMENTAL ASSESSMENT PHASE TEAM

Dr. Brian Colloty and Dr. Godlove Enongene both of CES, aided by Mr. Tim Healy and Mr. Agnès Joignerez (AQUATERRE) conducted the marine specialist assessment of the proposed port expansion.

Dr. Colloty, liaised with the proponent, specialist team and was tasked with the production of the report. During the site visit, he provided input in the noise and visual assessments. Dr. Paterson reviewed the final report.

Dr. Enongene, provided input to the noise and visual Assessments, and aided as translator in the interviews with key stakeholders and Port Authorities.

Mr. Agnès Joignerez of AQUATERRE, based in Madagascar, sourced and reviewed past investigations within the region. Mr. Healy provided local input and review of the AQUATERRE reports.

CHAPTER 2 STUDY METHODOLOGY

2.1 LITERATURE REVIEW

Prior to departure and during the site visits, background documents and information were obtained from various sources within Dynatec and the Port Authorities. Information obtained from the Port Authorities included persons such as the Port Captain and Director of Infrastructure and Management and Director of Marketing and Communication, who also supplied technical detail on the current port facilities. Dynatec supplied information regarding the proposed infrastructure development, aided by Sandwell.

The following list of organizations and the relevant personnel have aided in the production of this report, as sources of current information and documentation:

Antananarivo

- CNRE - Dr. Jean Maharavo
- Direction des Impacts Sociaux et Environnementaux – Mr. Harizo Rasolomanana
- Direction Maritime, Ministère des Travaux Publics et des Transports – Mr. François Marc Turpin, Conseiller technique
- GAPCM – Mr. Ramoraseta SG
- ONE - Mme Lalatiana
- Réfrigipêche Toamasina – Mr. Didier Barcelo (DG)
- SAGE Antananarivo – Ex Cellule Environnement Marin et Cotier de l'ONE - Mme Hajanirina
- VOARISOA - Mme Voahangy, Directrice

Tamatave (Toamasina)

- Port de Toamasina Port Captain – Mr. Avellin
- Port de Toamasina/Direction des Opérations - Mr. Séraphin Impali
- Port de Toamasina/Marketing Department – Mr. Rajerison & Mr. Rakotonirina
- SAGE Toamasina – Mr. Williams

During the CES sites visits both Mr. Avellin (Port Captain) and Mr. Rakotonirina (Port Marketing Director) were available for interview. They provided documentation regarding the present Port capacity and safety standards. It was indicated that although the Port of Toamasina does prescribe to materials handling standards and practices of the IMO (International Maritime Organization), no Occupational Health and Safety systems are active within the remainder of the port. It was also indicated that, although no major oil or fuel spills had occurred in the recent past and that suitable response kits were at

hand, these would not be able to cope with any further increases in shipping traffic. Mr. Avellin, further stated that should the Ambatovy project go ahead, that they would welcome any assistance in upgrading the standards of the Port.

2.2 FIELD TECHNIQUES AND SPECIALIST INPUT

A qualitative assessment of the state of the marine habitats found within the confines of the port was made based on interviews and daily visual observations. A noise level assessment was conducted throughout the port and city environs. An assessment of the visual sense of place assessment was also conducted.

CHAPTER 3 ENVIRONMENTAL DESCRIPTION

3.1 STUDY AREA

The city of Tamatave lies on the east coast of Madagascar in the Province of Toamasina. The Port of Toamasina acts a major supply and export facility in the country. The coastline is exposed with sandy beaches and several estuaries are located in the immediate vicinity, e.g. the Ivondro to the south and Ivoloïna to the north. The East coast of Madagascar experiences high annual rainfalls of approximately 3500 mm per annum, which results in high levels of freshwater input into the marine environment from these river systems. The East coast is wet for much of the year, as it is exposed to the trade winds, which are forced to rise as they meet the steep eastward-facing escarpment. The city experiences an annual rainfall of ca. 3,200 mm (Table 3.1.1). Rainfall can occur throughout the year and on average the region is affected by three tropical cyclones each year.

Table 3.1.1: Average monthly rainfall for Tamatave measured for the period 1889 to 1989 (SOGREAH, 2003).

Average Monthly Rainfall (mm)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
405	371	483	309	236	266	266	205	133	121	152	289

The port has been active for approximately 75 years, and nearby terrestrial and coastal areas have been transformed by the resulting industrial, commercial and residential areas of the town. Land around the port is covered with hard engineered surfaces, while the port area is subjected to pollution from vessels, accidental fuel spills, drainage from the hard surfaces and various other forms of land based waste from the surrounding region (SOGREAH, 2004). Under these conditions, ecological conditions can be considered as severely degraded.

Toamasina is constructed on a coastal sandy plain (5-6 km wide). The plain has developed between the sea on the east and a cliff on the west (BCEOM, 2003). The area lies upon a indistinct dune sands and coastal soils. The coastal plain is formed from a sequence of littoral fronts through fluvial depositions, which have migrated towards the sea (AQUATERRE, 2003).

This coastal plain is bordered by coastal coral reefs and islets which are located in a parallel line to the coast at depths of 20 to 40m (AQUATERRE, 2003). Due to these hard marine surfaces and the local sea movements, two coastal extensions have formed along the littoral zone. Hastie reef in the SE was used as the foundation of the port and the old town. The second extension of the town is protected by the Grand Recife, which currently forms Tanio Point, which allowed for Tamatave town to extend northwards.

Toamasina's coastline is therefore not representative of a uniform and rectilinear littoral zone due to the presence of reefs (BCEOM, 2003). As a result of the orientation of the mouth of the Ivoloïna River, there has not been any significant littoral movement to the north or south. Swells move perpendicular to the coast in this zone generating stratification between the beach and the shallow seabed. Tanio Point is a coastal extension formed by the protection of the Grand Recife. Its erosion has played a key role in dynamic sedimentary processes inducing changes over time. One of the causes for this regression is possibly linked to the construction of the coastal protection in front of the pass, which has created a sediment trap in the southern section of the bay and a subsequent deficit of sediments in the northern sector. Cyclones result in very important resetting events, which can cause coastal erosion amounting to tens of meters within a few hours. These littoral sediments are carried offshore and deposited in waters of 5m or more (BCEOM, 2003).

3.2 IMPORTANCE OF THE PORT

The Port of Toamasina is the principal port of Madagascar, accounting for nearly 80% of the country's international trade (IFC, 2004). The port is virtually a monopoly, as no other ports on the island are suitably developed for large amounts of containerized traffic. The port is about 370 km from the capital Antananarivo and is connected via railway, road and scheduled internal flights (IFC, 2004). It has been estimated that 80% of the activities in the town of Toamasina are directly related to the port (AQUATERRE, 2003).

The port is currently managed by the Société d'Exploitation du Port de Toamasina (SEPT) a state owned company (IFC, 2004). This company reflected an annual turn-over of almost 60 billion FMG in 2001, and contributed to a fifth of the town council's budget (2 billion FMG/year) (MinATV, 2001). SEPT is currently being restructured within the context of the reformed port legislation (IFC, 2004).

Presently, SEPT employs approximately 1760 permanent employees, with the same number of casual workers on daily basis (IFC, 2004). The port is therefore an important source of employment in the town (AQUATERRE, 2003). For the period 1992 to 2003, total trade through the Port increased from 1.25 to 2.55 million tons. International trade represents more than 86% of these figures, while the remaining 14% is generated by national goods (IFC, 2004). During the last 10 years, conventional and containerized goods represented between 55 and 65 % of the total traffic, the rest being oil imports (IFC, 2004).

On-going reforms

Currently, the Government of Madagascar is reforming the port sector, in particular the management structures of Toamasina port. Until recently, SEPT, a State company i.e. 100% capital, was responsible for all commercial activities (handling, stocking, pilots, tugs, and inshore piloting). The reform Law No. 2003-025 of September 2003 aims to:

- Create a public owned port authority: la Société du Port à Gestion Autonome de Toamasina (SPAT).
- Initiate the concession of commercial port activities (beginning with the container terminal, while other activities will be controlled by SEPT during the transitional phase).

In June 2005, the state of the reform process was as follows:

- Container terminal was put out to concession: contract signed with ICST and effective from autumn of 2005 with 350 employees from SEPT being transferred to this company.
- SPAT was created and the process of transferring employees from SEPT to SPAT was underway.
- Modified status of SEPT, which removes its role as Port Authority and allows for the concession of commercial port activities.

Port statistics

Table 3.2.1 presents a summation of the goods handled by the Port of Toamasina in comparison to other Malagasy ports (Scetauroute International, 2004). These figures show that the Port of Toamasina handles 82 and 85% of containerized goods and fuels, respectively on a national basis. The port also dominates the control of dry non-containerized goods by handling 50% of the national traffic.

Table 3.2.1: Total goods handled (1000s of tons) in the Toamasina Port in Comparison to other Malagasy ports (Scetauroute International, 2004).

Year / Ports	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
TOAMASINA	1 208	1 083	1 076	1 288	1 422	1 558	1 477	1 807	1 937	2 102	2 369	2 370	1 633	2 543	2 403
MAHAJANGA	180	166	151	211	205	228	251	210	222	247	310	410	356	Information not available	
ANTSIRANANA	255	231	284	244	321	381	296	298	453	403	192	190	207		
TOLIARA	84	56	65	79	75	72	58	73	70	84	96	150	135		
AUTRES	306	229	250	265	258	264	253	248	246	218	273	268	266		
TOTAL	2 032	1 765	1 826	2 086	2 280	2 503	2 335	2 637	2 929	3 055	3 240	3 388	2 597		

Source: APMF, SEPT and estimations by Scetauroute International

3.3 THE HARBOUR AND BAY ENVIRONMENT

Port Sediments

The foundation soils of the port quays vary due to the presence of coral reefs (SOGREAH, 2004). Moles A and B are constructed on sediments within the protection of the Grand Reef, where their foundations lie on fine sand with layers of sandy clays and coral debris. Mole C is constructed on the edge of the reef where its foundation is composed of disaggregated coral.

The beach fronts have sediments with an average diameter of between 0.2 and 0.35 mm (LCHF, 1984). Sediments become finer as they move offshore (0.10 to 0.15 mm from between -5 m to -10 m) due to granulometric sieving during the movement of the coastal sediment profile. At depths of 15 m, the sediments become more clayish. It has been noted that sediments in the bay are much finer, as the area is less agitated due to protection from the reef and seawall (BCEOM, 2003). At depths of less than 15 m, sands are principally composed of quartz carried from the land (fluvial deposits and erosion of former coastal edges). Offshore, seafloors of less than 20 m, are mostly muddy sands, composed of an equal mixture of quartz and limestone, which are depositions from weathered coral reefs (calcium carbonate) (BCEOM, 2003).

Port and Marine Pollutions sources

The marine habitats within the Port of Toamasina are highly degraded due to pollution originating from harbour-related activities, industry and the town of Tamatave itself. There appears to be no plan for the control of domestic and industrial waste, and general refuse is widespread, ending up in the streets or in the Pangalanes Canal.

3.3.1 INDUSTRIAL SOURCES

Industries are concentrated within the port and the south and south-western parts of the town (AQUATERRE, 2003; CUT, 2004). Based upon the list of formal companies provided by the Ministry of Industry, there are also three printing works, plastic goods suppliers, cement manufacturer and various chemical product suppliers. Potential sources of industrial pollution (AQUATERRE, 2003; GLW, 2004; CUT, 2004; & VOARISOA, 2004) include:

- petrol refinery (GALANA);
- petrochemical industries (SOMALAVAL : paints, SOAM : industrial gas & medical supplies ; VARATRAFO : matches ; PROLUMA : lubricants, S2PC : paints & varnishes);
- palm oil;
- port activities (in particular : careening, ships' waste and fuel transshipments);
- textiles (CHAMPVILLE, SITEX, etc.);

- agro-industries (SOPRAL, SOMAPALM, etc.); and
- industrial supplies: cement (HOLCIM) and steel/metal fittings (IMAE, CIMELTA JEUMONT, SMEM, etc.).

The principal chemical products utilized in Toamasina thus include (VOARISOA, 2004): sodium chlorate, acetylene, butane, petrol products, solvents (white spirit, butane), resins, ethanol, red and white phosphorus, calcium carbide, nitrocellulose, sodium nitrate, ammonium nitrate, caustic chlorates, tetraethyl lead, red lead paint, cobalt 60, triazines, aryloxyacids, carbofuran, triadimefon, iridium, phosphoric acid, caustic soda, sulphuric acid, acetic acid, manganese dioxide, xylene, and ethylene glycol.

3.3.2 SANITATION

Toamasina is serviced by a single sanitation network (collecting rain water and waste water), which has aged and is under capacity (CUT, 2004). Two major outlets occur; namely the Pangalanes Canal and the North Canal – which finally flow into the Indian Ocean. The Pangalanes Canal also acts as the final stormwater receptor for the majority of the town, including the industrial zone in the south (CUT, 2004).

A significant proportion of the population depends on open latrines or containers (bucket systems) for their personal needs. Informal settlements resort to the use of open public areas along beaches or water courses (AQUATERRE, 2003). The current drainage/sanitation system dates from colonial times of which only 50% remains in partial working order.

Household solid waste for Toamasina is estimated at 100 m³/day (CUT, 2004), which is collected regularly by private collection services. The refuse is dumped at two main sites located less than 5 km north of the town near the main road (RN2) and at Betainomby (AQUATERRE, 2003). These disposal sites were never subjected to a site selection process and are poorly managed (CUT, 2004). Industries have to resort to their own waste disposal systems and/or sites (CUT, 2004, MinATV, 2001). Dough like wastes (Photo Plate 3.1) from the refinery are also dumped without precaution on land adjacent to the Pangalanes Canal, south of the refinery (GLW, 2004). The refinery has, in the interim, installed a waste depot within Galana's perimeter fence.



Photo Plate 3.1: A Photo taken during the CES site visit near the refinery, where effluent has leaked into the surrounding area.

General refuse is also informally dumped along the beaches or along the Pangalanes Canal.



Photo Plate 3.2: Photos taken during the CES site visits indicating the various areas and types of refuse disposal and informal sanitation systems.

3.3.3 POLLUTION IN THE PANGALANE CANAL

Sources of pollution in the canal include discharges of untreated waste water from the town, Galana Refinery, HITA palm oil factory, the Port, SMEM metal container factory (GLW, 2004) and household waste. Principal pollutants which have been identified include organic materials, oils and greases, fuels, phenols, nitrates, heavy metals, solvents, phosphates and microbial pathogens (VOARISOA, 2004; Ratsifandrihamanana, 2000).

The Galana Oil Refinery was audited recently to conform to Malagasy environmental legislation (MECIE) (GLW, 2004). Issues raised were system leaks due to poor installation or vandalism and uncontrolled atmospheric emissions (CO₂, SO₂, CO, SO_x, NO₂, NO_x, dioxine, furannes).

The Isarakofafa Industrial Zone is currently being planned between the refinery and Dynatec's proposed factory, linked by a new road leading to Galana (GLW, 2004). Until now land development has consisted of land drainage and the construction of internal roads. Industries in this zone will generate pollution which needs to be accounted for in the future.

3.3.4 POLLUTION OF THE IVONDRO RIVER

The Ivondro River is affected by dumping of what has been described in past reports as "oily sludge" of unknown composition. It can be assumed that this has an industrial origin. The river also carries high sediment loads (Suspended Solids), due to agricultural practices within the upper catchment and floodplains of this system. The Pangalanes Canal also joins the mouth of this river, which contributes additional pollutants (VOARISOA, 2004).

3.3.5 POLLUTION OF GROUNDWATER

Sources of pollution of groundwater include the infiltration of industrial waste, fertilizers, burying of household wastes and pit latrines. Contaminants associated with these pollution sources include fuels, phenols, nitrates, pesticides, solvents, heavy metals, and microbial pathogens (VOARISOA, 2004).

3.3.6 MARINE POLLUTION

The sources of marine pollution include industrial activities, the port activities (cargo, re-fueling/loading, surface water runoff) and inadequate urban sanitation/drainage (SOGREAH, 2004). All the pollutants affecting the Pangalanes Canal, Ivondro River and other watercourses ultimately enter the marine environment (Photo Plate 3.2) (VOARISOA, 2004).

Table 3.3.1 presents the results of water quality analysis of samples taken from the Pangalanes Canal and the ocean (VOARISOA, 2004). The exact locality for the sampling was not given.

Table 3.3.1: Results from analysis and observations of seawater and water in the Pangalanes Canal (VOARISOA, 2004).

Parameters	Max. observed values	Observation sites	Origin of pollution	International Standards (World Bank)	Comments on water quality
T °C	18,5	Grand reef Toamasina		-	
pH	8	Grand reef Toamasina		6 - 9	Acceptable
TSS mg/l	860 ^{*1}	Quay III	Industrial	50	Exceeds
	5,6	Port I	Industrial		Acceptable
	7,2	Port II	Industrial		Acceptable
BOD5 mg/l d'O2	335 ^{*1}	Quay III	Industrial		Exceeds Guidelines
	15	Port I	Industrial		
	80	Port 2	Industrial		
COD mg/l d'O2	930 ^{*1}	Quay III	Industrial		Exceeds Guidelines
Colour		Quay III & Pangalanes	Industrial		
	35 ^{*1}				
Total Hydrocarbons mg/l	35,9 ^{*1}	Pangalanes	Industrial		
	1	Port I	Industrial		
	2,6	Port 2	Industrial		
Nitrate (NO3) mg/l	5,2	Port I	Industrial		
	4,5	Port II	Industrial		
Total coliforms	20 colonies /l ^{*2}	Water at rivermouth of Pangalanes Canal	Domestic		
	321 colonies /l ^{*2}	Pangalanes Canal glassworks Tanambao	Domestic		

Laboratory used for analysis was not given (probably a local lab); protocol and type of analysis were not given;

*1= sampling in December 2003

*2= sampling in September 2001

Others: February 2004

Port activities

Port activities including maritime transport and boat/ship repairs.

Larger vessels have the means to separate their waste fuels, lubricants, greases, cleaning agents and water. While smaller vessels at berth or being repaired do not always have the available bilge water separation equipment (SOGREAH, 2005). Sump oils, wastes and contaminants are thus pumped directly into the water via the bilge pumps. Bilge water composition is not really known and varies according the state of vessels and their maintenance. It has been estimated that diesels and oils could represent 10 to 50% of all organic waste material in the Toamasina dockside water (SOGREAH, 2005).

Ship and boat repairs occur at the end of Dock 2B (Photo Plate 3.3). Operations include cleaning, painting, de-fouling, and mechanical work. At present, there is no system in

place for the containment and treatment of waste on site (SOGREAH, 2005). The surface of the water within this area is usually covered with oils, paints and various other products being dumped directly over the dockside without any treatment. The future, GAPCM slipway rehabilitation project, proposes a treatment system for surface water (sieving, de-oiling, separation, and disposal) together with solid waste management system (SOGREAH, 2005).

The principal contaminants are thus heavy metals and organic compounds associated with anti-fouling paints, fuels (SOGREAH, 2005) and zinc used as anticorrosion protection on metal structures (SOGREAH, 2004).

TBT is the favoured antifouling paint in Madagascar, although some are copper based. No guidelines or specifications exist in Madagascar regards the use of antifouling paints and is left to the vessel owner's discretion, whose preference is based on technical issues and cost. There are indications that TBT will be preferred in future (SOGREAH, 2005).

Seawater samples from Dock 2B and near the bay at the entrance of Docks 1 and 2 were taken in January 2005. The results are presented in Table 3.3.2. It is evident that copper, nickel and iron values diminish from Dock 2B towards the bay (SOGREAH, 2005). However it can be seen in Table 3.2 that Iron exceeds both Madagascar and World Bank Guideline at sites D1, D2, D3 and D4, while Nickel exceeds the same guidelines at Sites D1 and D2. Copper exceeds the World Bank Guidelines (Table 3.3.2) at sites D1, D2 and D3. This indicates that these sites during that survey had contaminated water not suitable for aquatic health due to the use of heavy metal based antifouling paints.

Table 3.3.2: Analysis of heavy metals in the seawater at Dock 2B (4 samples) and near the bay (3 samples) in 2005 (SOGREAH, 2005)

Sample	Cr (µg/l)	Mn (mg/l)	Fe (µg/l)	Ni (µg/l)	Cu (µg/l)	Zn (µg/l)	As (µg/l)	Br (mg/l)	Pb (µg/l)
D1	<15	0.7	60	400	600	<10	<8	77	<7
D2	<15	1.2	10	200	400	<10	<8	76	<7
D3	<15	1.4	20	<10	700	<10	<8	44	<7
D4	<15	0.7	20	<10	<9	<10	<8	71	<7
B5	<15	0.8	10	<10	<9	<10	<8	76	<7
B6	<15	1.2	10	<10	<9	<10	<8	55	<7
B7	<15	0.4	10	<10	<9	<10	<8	80	<7
Madagascar Water Quality Guidelines ¹	2	5	10	2		0.5	0.5	-	0.2
World Bank Water Quality Guideline	0.5	-	3.5	0.5	0.5	2	0.1	-	0.1
Natural Sea Water ²	0.0002	0.0004	0.0034	0.0066	0.0009	0.005	0.0026	-	0.00003

Analysis prepared by INSTN laboratory (Madagascar) using fluorescence spectroscopy; protocol and methodology were not given.

¹ Portant classification des eaux de surface et réglementation des rejets d'effluents aqueux, Le Ministre de l'Environnement, Vu la Consulation, Vu la loi no 90.033 du 21 Decembre 1990 Vu le decree no. 2003-464 du Janvier 2003.

² <http://www.seafriends.org.nz/oceano/seawater>; Karl K. Turekian: Oceans, 1968, Prentice-Hall

Port basin sediment quality

During the GAPCM slipway rehabilitation project (SOGREAH, 2004) quayside sediment samples were collected. Only sediment surface samples were collected with the analyses conducted by Drome Laboratory in France. The constituents analyzed included:

- total organic carbon;
- qualitative review of metals;
- total hydrocarbons; and
- polycyclic aromatic hydrocarbons (PAH's).

A summary of principal results is presented in Table 3.3.3

Table 3.3.3: Results from analysis of sediments near quaysides (SOGREAH, 2004) in mg/kg obtained from dried samples.

Mole & Sample Number	TOC	Copper	Lead	Zinc	Nickel	Arsenic	Chrome	Heavy HCs	ΣPAH
A1	14.0	79	700	640	22	15	28	ND	2.92
A6	19.4	410	56	420	53	46	37	ND	2.75
A7	13.2	56	540	220	22	14	33	ND	1.94
A8	13.9	43	52	95	18	9	27	392	0.91
B1	20.4	52	180	150	36	10	65	345	2.04
B2	7.9	370	160	410	14	14	21	ND	0.33
C7	39.5	92	250	400	62	29	140	ND	0.62
ANZECC 1998 Guidelines (mg/kg)	-	270	220	410	52	70	80		0.5

Analysis done by Laboratoire Départemental de la Drome (France); protocol was not given; see extraction et analysis method in Annexe 4 ; Attention : qualitative summary of metals

TOC : Total organic compounds

ND : not detectable

HC : hydrocarbons

PAH : Polycyclic Aromatic Hydrocarbons

Based on the ANZECC (1998) guidelines for metals within sediments, various localities indicated in Table 3.3.3 exceed the set Maximum Levels and would thus pose a risk to marine and human life.

SOGREAH (2004) rationalized the high values present in a large proportion of the samples as follows:

- Copper: use of Cu₂O in anti-fouling paints.
- Lead: use of tetraethyl lead in fuels.
- Zinc: zinc base used in anti-corrosive paints.
- Heavy hydrocarbons and PAHs: jettisoned fuel and petrochemical industries.

An indication of the high chrome values was not given, but due to the locality of the Chrome Ore Terminal at Mole C, it can be assumed that the terminal is the major source as this portion of the Port handles approximately 50 000 tons of Chrome ore per year. The remaining sites all occurred within the vicinity of the smaller moles, where the maintenance and repair of boats and ships is ongoing.



Photo Plate 3.3: The maintenance area along Mole A, with a ship being painted and large quantities of paint being spilt.

Dredging of the main harbour basin has never taken place and it does not appear that sediment build-up in the vicinity of the breakwater is a problem. Strong tidal currents at the entrance and cyclonic seas may account for the fact that sediments do not accumulate in this region. Dredging has, however, occurred on the shoreline opposite Mole A where sediment encroaches on the channel. This operation was conducted five years ago and had resumed during the August 2005 site visit. The spoil is dumped on the beach in front of the fishing club (Photo Plate 3.4), which was later hauled away to an unknown destination. The decant water was allowed to drain back into the port area. Although this aspect does not have any bearing on the current study, this practice should not be condoned and a safe spoil disposal site needs to be found.



Photo Plate 3.4: The dredging operation which occurs to maintain the channel for Mole A. Spoil is pumped onto the beach and decant water returns to harbour.

3.4 BIOLOGICAL ENVIRONMENT

3.4.1 PORT

During the study of the proposed port rehabilitation (SOGREAH, 2004), a photographic assessment of the marine environment was conducted during the dive surveys of the quay engineering. The seabed alongside the docks consisted of muddy sediments often covered in solid waste originating from the various port activities (SOGREAH, 2004). The substratum was composed of small grain sizes silts presenting poor habitat for fauna. The environment is thus in a state of advanced degradation supporting mostly sessile organisms. Fauna seen during the dives includes the following species:

- *Platax pinnatus*
- *Zanclus comutus*
- *Acanthurus xanthopterus*
- *Caesio caerulaurea*

- *Scarus sp.*
- *Canthigaster velentini*
- *Oursin echinoderme*
- *Corail anémone*
- *Chromis sp.*
- *Pomacanthus sp.*
- *Foorcipiger longistrostris*
- *Chaetodon melannotus*
- *Pomacanthus semicirculatus*
- *Plectorhincus sp.*

No conservation needy species were encountered, which occur on nationally or internationally recognized conservation worthy species lists (AQUATERRE, 2005).

3.4.2 TOAMASINA BAY

Marine

Ecological data for the bay is limited (SOGREAH, 2004). From an ecological point of view the bay has limited species richness. The average depth of the bay is limited to 10 m and the seabed is dominated by sandy to clay sediments. The environment is relatively dynamic (strong movements, important erosion and sedimentary processes, turbid waters) resulting in an ecosystem which has a low sensitivity (AQUATERRE, 2003).

Two coral reefs are situated at an immediate proximity to the port namely; Hastie Reef and Grand Reef. Hastie Reef has been transformed through the construction of the port, by being used as the port's base. Grand Reef has been used by SEPT to stock dredged material (SOGREAH, 2004). Furthermore the reef is not listed in the Indian Ocean Commission's environmental monitoring programme, as it has no intrinsic value for either fishing or tourism (SOGREAH, 2004). The 2004 / 2005 coral reef surveys conducted by ORI and CES, confirmed the degraded nature of these reefs, where portions still exist (Schleyer & Celliers, 2005).

Coastal Environment - Terrestrial

The formation and role of the marine sediment bypass system off Tamatave were studied in detail by AQUATERRE (2003). Although the construction of the Port has hampered the continued transport of sediment along the coastline, the major impact on the landward side of the coastal environment has been the development of road and residential infrastructure.

Between 1900 and 1981, the erosion of Tanio Point has been steady and progressive (BCEOM, 2003), principally due to movement of sediments and reset events such as cyclones. Cyclonic events can produce sudden losses of 10s of meters of shoreline. The

construction of the port's seawall in 1930 and its extension in 1970 appears to have further accelerated the erosion of Tanio Point. In 1981, this loss was halted with the rock protection placed along the point. The north coast has experienced similar erosion, which culminated with the destruction of the coastal road and resulting in the construction of seawalls by inhabitants.

The principal natural and anthropogenic causes affecting the evolution of the coastline are as follows (BCEOM, 2003):

- Geomorphology: sensitive coasts (sandy), reefs (hard points causing diffraction, refraction and extensions).
- Oceanography: agitation (coast/seabed profile change, sediment shift, loss of beach sections during cyclones).
- Sedimentology: movement of the sediment profile and coastline.
- Human impacts: construction of artificial dykes (modifying refracting/diffracting conditions in the bay), coastal constructions (promote profile movements during cyclonic conditions).

AQUATERRE (2003) described the coastline evolution through the analysis of a series of aerial photographs, north of Tanio Point from 1950, 1961, 1985 and 1995. Table 3.4.1 presents the losses or gains in coastline from the measurements at 4 points on the aerial photographs overtime.

Table 3.4.1: Coastal evolution between 1950 and 1995 (AQUATERRE, 2003). –ve = coastal regression (erosion); the sign +ve = coastal advancement towards the sea (accretion).

Measurement Localities	1950-1961	1961-1985	1985-1995	Cumulative Total
Point 1	- 55	+ 5	- 140	- 190
Point 2	0	+ 33	- 59	- 26
Point 3	- 38	+ 16	- 43	- 65
Point 4	- 30	+15	- 17	- 32

Source: FTM Aerial photos 1950, 1961, 1985, & 1995

From the above analysis it was evident that the Toamasina coastline can be described as two distinct regions (Maevalaza, 2001):

- The south, the bay of Toamasina - From the hospital (located just to the south of Tanio Point) until the port, the coastline is slowly accreting and will over time approach the port.
- The north, a straight coastline - The regression of Tanio Point has more or less been halted with rock protection. Meanwhile the northern coast continues to suffer from severe erosion.

During the site visit by CES (August 2005) the following plant species were documented:

- *Ipomea pres-capre* (Dominant Creeper)
- *Stenotaphrum spp* (Grass)
- *Sporobolus spp* (Grass)
- *Crotalaria spp*

These species have limited conservation importance based on the IUCN Red Data criteria (Ver 3.2a) and their habitat requirements are not threatened by the current activities or the proposed development. These species are, however important dune sand pioneer species, adapted to the mobile beach front environment. These plants stabilize the sands and prevent erosion of the beach areas by wind and wave action.

3.5 SOCIO-ECONOMICS AND TOURISM

3.5.1 POPULATION AND DEMOGRAPHY

The 1993 National census indicated that the urban population of Toamasina (Toamasina I) totaled 127,441 people (AQUATERRE, 2003). Table 5.1 below indicates the population growth trends between 1999 and 2003 for the Districts of Toamasina I (Toamasina Town), Toamasina II, as well as Atsinana (this region encompasses the Districts of Toamasina I & II, Brickaville, Antanambao Manampontsy, Vatomandry, Mahanoro, and Marolambo located south of Toamasina and along the coast). This equates to a 21 and 25% population growth respectively over the five year period, which is lower than the global norm for the same period (USAID, 2003) (Table 3.5.1).

In 2000, the total population for the entire Toamasina Province was estimated at 2,373,737 inhabitants (Rakotovoarison, 2001).

Table 3.5.1: Annual population numbers for the period 1999 to 2003 (SAGE, 2005 & USAID, 2005)

	1999	2000	2001	2002	2003
Toamasina I	168 048	173 633	179 424	185 353	214 275
Toamasina II	160 129	165 423	170 915	176 538	214 199
Région Atsinana	954 599	1 012 841	1 057 899	1 100 132	1 171 924

Source: Renseignements politico-administratifs des communes (SPAT), December 2003

3.5.2 EMPLOYMENT

MinATV (2001) estimated that the number of people employed fulltime was approximately 68,900 of which 4,403 were Government civil servants. In relation to companies and other enterprises, the port was, and still is, the largest employer in the town. The remaining employment opportunities were attributed to industries, import-export companies, trading companies, commercial and artisanal fishing, and hotels and restaurants.

Industry

As discussed previously Tamatave has approximately 27 industrial companies operating within the region. Due to the proximity of the port to the airport and various transport routes, industrial development in the town was favoured. These are associated with processing industries, which are highly dependant upon the port and have created a sizable employment opportunity for both the skilled, unskilled markets (AQUATERRE, 2003).

Commercial fishing and artisanal activities

Réfrigépêche Est is the only commercial fishing company in the town (AQUATERRE, 2003). This company possesses a fleet of large trawlers and uses advanced fishing techniques. Catches such as shrimps and camarons are exported directly to Europe. In 2000, Réfrigépêche Est exported 429 tons (MinATV, 2001), while the fish by catch was sold at local markets. The fishing zone for this company extends from Antongil Bay to the south of Toamasina.

Artisanal fishermen, using motorized boats (< 30Hp) together with relatively advanced fishing techniques (nets, drop lines, hooked lines, etc.) also contribute a significant amount employment opportunities.

Traditional fishing

In the Toamasina I and II region, this activity includes both sea-fishing freshwater fishing (AQUATERRE, 2003). Both activities rely upon local resources, and in the majority of cases, fishermen are dependant upon other economical activities. Traditional fishing uses simple equipment: non-motorised pirogues, fishing on foot, mess nets, and fishing canes.

Freshwater fishing is practiced within the numerous inland waterways, such as the Pangalanes Canal (AQUATERRE, 2003).

Traditional fishing is constrained by the physical form of the coast (straight continental shelf and rectilinear edge exposed to wind making navigation dangerous during certain times of the year). However, there are 5 sites used for traditional fishing in Toamasina,

which are located just north of Tanio Point (AQUATERRE, 2003). Average income for this sector was estimated at 300,000 FMG (MinATV, 2001). Catches are unloaded on the beach and sold at various markets in town.

The key fishing areas are indicated in Figure 3.5.1 using information obtained during interviews with local fishermen within the region (Fisheries Specialist Study – CES Marine).

Tourism and the importance of the coastline

Tourism development in Toamasina Province is assisted by the Inter Regional Department for Tourism. Table 3.5.2 presents the number of hotels and restaurants in the Province's and in the town.

Table 3.5.2: Hotels and restaurants in the Province of Toamasina including the Town of Toamasina

Toamasina	Hotels			Restaurants	
	Rooms	Bungalows	Number of hotels	Number of restaurants	Sittings
Province	800	900	150	167	7580
Town	545	110	42	61	2850

Source : Direction Inter Régionale du Tourisme Toamasina, November 2002.

Tourism growth expressed as the annual increase in numbers of visitors shown is in Table 3.5.3 for the period 1994 to 2000. This data further indicates that approximately 5800 tourists per year visit the Province, of which 17% are foreign nationals. Several years have shown marked decreases in tourist numbers; however these fluctuations could not be correlated to any major storm or cyclonic events.

Table 3.5.3: Total number of annual visitors to Toamasina Province, shown per tourist category.

Visitors	1994	1995	1996	1997	1998	1999	2000
Non residents	2969	3222	3028	2734	2119	4821	2292
Foreign residents	851	596	621	428	142	658	3601
National residents	2059	2626	2272	476	225	4631	494
Total	5879	6444	5921	3638	2486	10110	6387

Source : Direction Inter Régionale du Tourisme Toamasina, November 2002

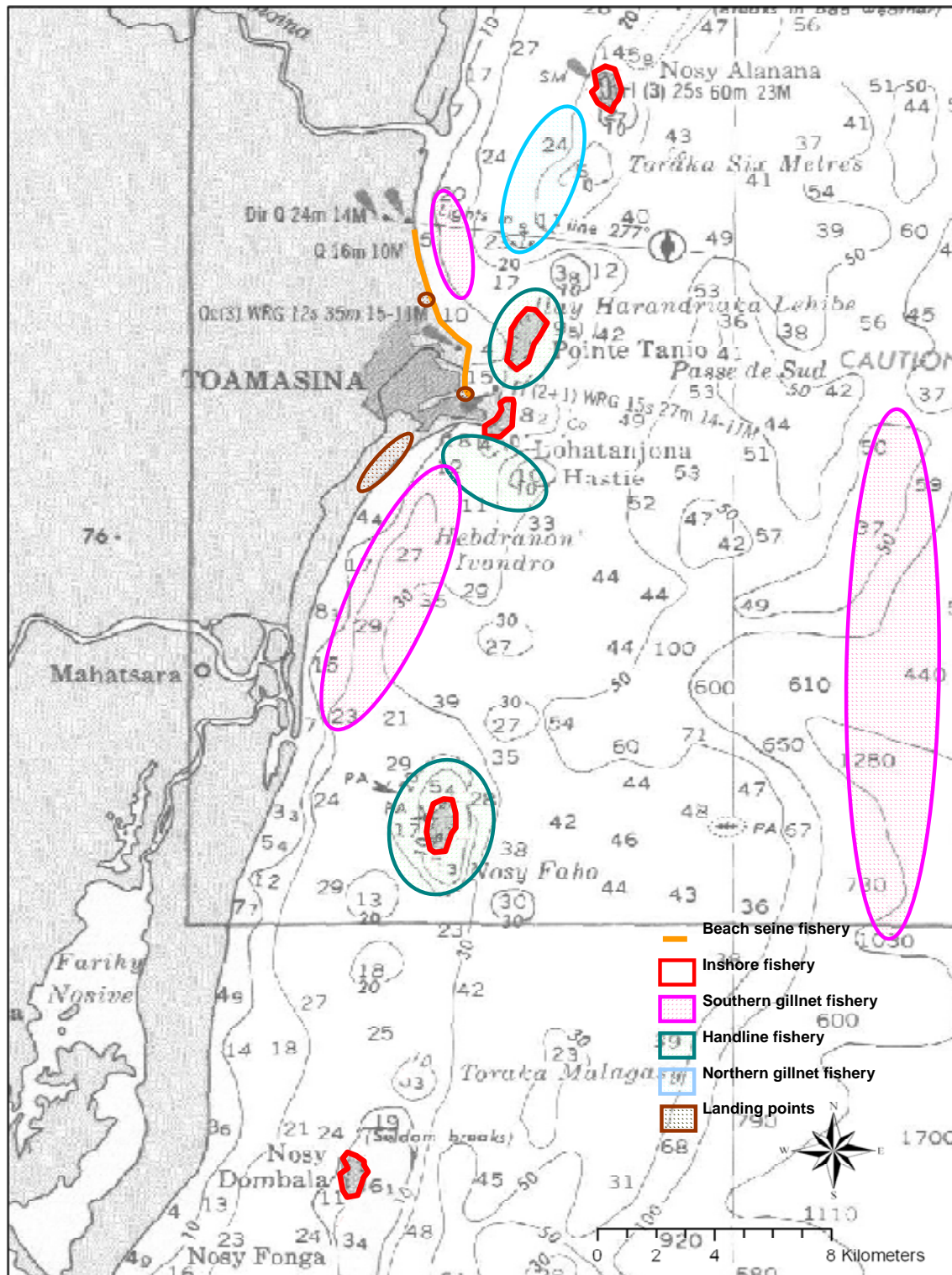


Figure 3.5.1: Map outlining key fishing areas around Toamasina

Tamatave itself is thus not a tourist center although the Province of Toamasina does have several major attractions. The major activities in Tamatave are related to the port. Tourists may visit the town for a few days on their way to other destinations on the island, but there is little on offer specifically for tourists. Local markets are geared towards the local population and only a few small shops sell more expensive crafts and local merchandise. A tourist camp (Eden Resort) was found in the village of Tanakala on the banks of the Pangalanes Canal. They offer limited accommodation as most of their patrons are day visitors who eat at their restaurant or go for a cruise along the canal (Photo Plate 5.1) and through the Ivondro estuary waterways down to Lake Nosive where they stop off at the village of Ampasindava to experience the local culture. Packages for a cruise, meal and transport to and from Tamatave are sold for 250 000 MGF, with overnight accommodation an additional 80 000 MGF. The busy period is May to December, but during the peak cyclone season (January to April) business is slow and restricted mostly to locals. Tourism in the Province follows a similar pattern although the quiet period is shorter, being restricted to February and March (Anon. 2002).



Photo Plate 3.5: The cruise boat used by the Eden Resort to transport tourists along the Pangalanes Canal and Ivondro waterways.

3.6 AMBIENT NOISE CONDITIONS

Observations regarding the ambient noise conditions were taken during the August 2005 site visit by CES. Noise level measurements were taken at similar times at the four localities over a three consecutive day period (Figure 3.6.1). The average levels (dBA - Lavg) were obtained over a five minute measurement period. Measurements were taken using a calibrated Tenmars TM 102 Noise Meter, between 12h00 and 13h30 during the day and between 20h00 and 22h00 at night.



Figure 3.6.1: The four noise measurement localities used in this study.

Table 3.6.1 shows the maximum and average day and night time noise values at selected sites within the port, along the beachfront, within the CBD (Central Business District) and along the main transport route to and from the port on the RN2, south of the Port Entrance.

Table 3.6.1: Maximum and averaged noise levels (dBA - Lavg) taken at four localities within the study area, for both day and night time periods.

Locality	Port		Beachfront		CBD		RN2	
	Day	Night	Day	Night	Day	Night	Day	Night
Maximum	87	71	78	78	89	81	92	67
Average	67	58	62	63	72	58	72	58

The locality which experienced the greatest day/night variation was the road leading to the Port Entrance on the RN2. The variation was due to the high number of container trucks queuing at the security check before entering the Port during the day. At any given time during the CES visit between 20 and 45 trucks were observed in the queue.

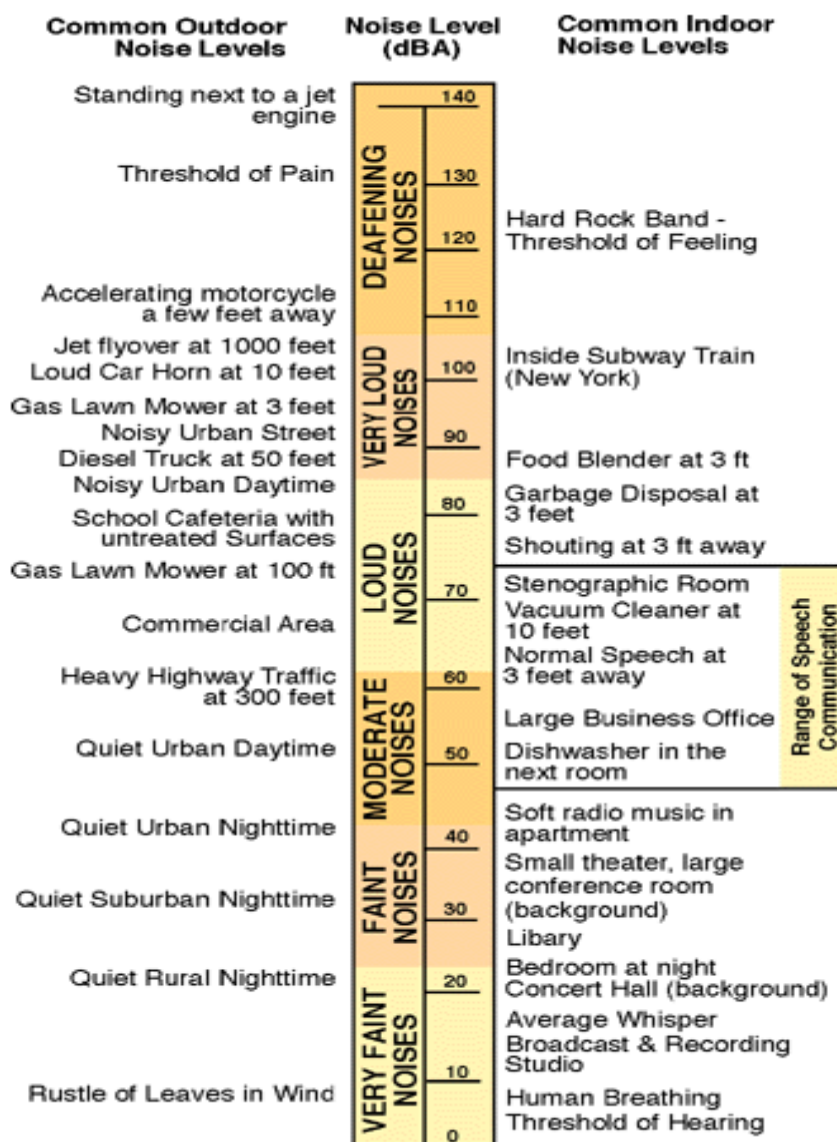
These vehicles were in various states of disrepair and the maximum noise levels were as a result of the both loud / customised hooters and sirens mounted to the trucks or missing exhausts systems. The numbers of trucks was lower during the night.

The locality which showed the least variation in noise levels, both average and peak values, was the beachfront. This was due to the constant sound of the ocean and the maximum values were as a result of the breaking waves.

The Port and the CBD would seem to have similar noise levels. Although the sources varied greatly, both experience a high level of traffic. The CBD, would seem to have slightly higher maximum level, due to the high number of two stroke mopeds / scooters. During the evening, vehicle traffic would decrease, however, from 20h00 the numbers of motorcycles would increase again, as this is a popular mode of transport for the youth, with a number of meeting areas along the beachfront and at clubs within the CBD.

This study did not take into account weather patterns, which also affect noise levels, i.e. there is a known correlation between a decrease in vehicular traffic (noise) and high rainfall periods (DEFRA, 2002). The results do indicate that there is limited variation in noise levels within the Port and its surrounds. This is supported by a number studies conducted within busy port regions, which experience high levels of noise, which are directly related to the associated road traffic and not generally as a result of the Port itself (NOAA, 2004).

The following graph indicates typical noise values, which are audible to humans (NOAA, 2004).



From the above graphic it is seen that levels measured in this study are representative and that the day time regions within the Port and along the RN2 area considered within the range of Loud and Very Loud Noises.

3.7 VISUAL ASSESSMENT – SENSE OF PLACE

Due to the public nature of the ocean front the proposed development could have a negative visual impact due to the short viewing distance between the port and the residences, roads and beach front. Visual impacts are impacts upon the views of the landscape of individual viewers and are defined as a function of the sensitivity of a

receiver and the magnitude of the change to that receiver's view. Visual impact assessment involves an evaluation of the visual impact of the proposed development and the identification of receptors that will be affected by the change to a given view. Significant thresholds of visual impacts on receivers were assessed and categorized as being of high negative to high positive as illustrated in Table 3.7.1. The CES conducted a broad visual assessment of the sense of place during field surveys based on the following:

- A visual reconnaissance of the study area;
- Description of the viewshed and landscape attributes;
- Photographic analysis with simplistic superimposition of elements of the proposed development; and
- Interpretation of available maps and the engineering designs.

Table 3.7.1: Characterization of visual impacts of proposals

Extent of Impact
High negative
Medium (moderate) negative
Low negative
Insignificant (Negligible)
Low positive
Medium (moderate) positive
Very positive

Identification of the nature of impacts

In reviewing and assessing the visual impacts of the proposed harbour expansion, the visual baseline was established by the extent of the harbour's visibility, and the surrounding landscape (Figure 3.7.1). Due to the flat topography of the region and extensive gardens, the views of the harbour are limited to the road and the first row of homes along the beachfront. The viewshed indicated by the green line in Figure 3.7.1 shows its limited extent, and that the harbour and beachfront is viewed by a limited proportion of the region.

Photo Plate 3.7.1, 3.7.2 and 3.7.3 were taken at the 3 observation points shown in Figure 3.7.1 and indicate not only the current view, but also the likely impact of additional ships at Mole B. This was done by superimposing a similar type of ship as if it were docked at the extended Mole B. The impact of the view (sense of place) was thus evaluated in terms the future effect of the mole extension and how it might be perceived by a viewer.

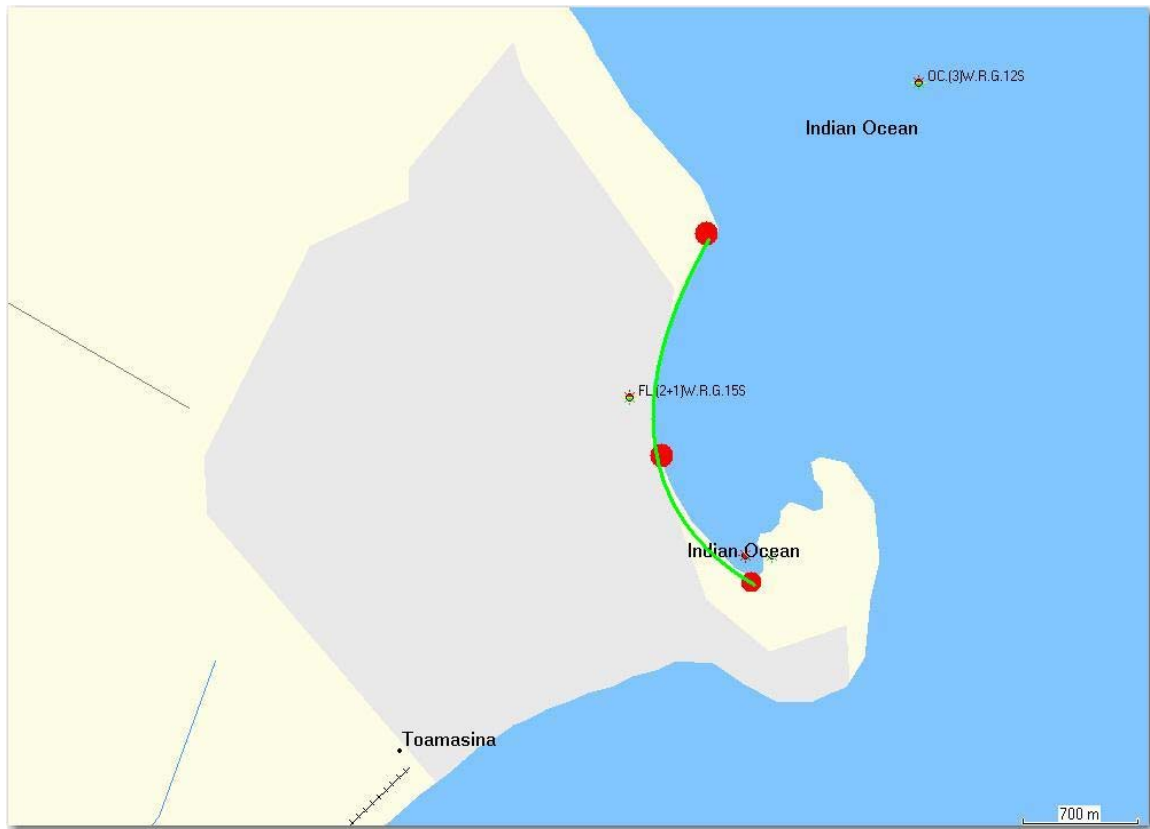


Figure 3.7.1: The narrow extent of the viewshed is shown by the green line, while the red dots indicate the observation points in the visual assessment.



Photo Plate 3.7.1: Position 1: viewpoint from the north of the harbour.



Photo Plate 3.7.2 Position 2: viewpoint from the west of the harbour.



Photo Plate 3.7.3: Position 3: viewpoint from the south and closest viewpoint to the harbour.

The visual impact of the proposed development have been assessed prior to the construction and the operational phase and includes cargo handling and transportation from the port, increased traffic levels on local roads, unplanned urban development around the port. The Zone of Visual Influence (ZVI) will however, be limited to the immediate surroundings of the port and harbour, from the beach, recreational facilities and residential buildings in the west and the ocean to the north. The sea, beach and coastal platform generally offer no visual absorption capacity and are therefore visually sensitive. The topography of the area is virtually flat with an altitude difference between 3 and 8m for up to 5 km into the hinterland (AQUATERRE, 2003). However due the density of the planted vegetation and houses, along the beachfront, the ZVI is further limited to only the first row of properties along the beach road.

The visual impacts of the proposed harbour expansion will include:

- Obstruction of views: the existing view is unlikely to be affected considerably by the proposed harbour development. The addition of extra ships to the existing view would consider subordinate or co. dominant with regards to visual contrast and therefore would not be significantly different from the existing surroundings as illustrated in the Photo Plates. The visual effect is expected to be low negative to negligible.
- From the west of the harbour, possible visual intrusions are the Handling Cranes, ships, harbour control building, oil tanks and conveyor structures. These structures already intrude on the visual landscape, being visible on the horizon in an otherwise level landscape (Photo Plates 3.71 to 3.7.3). The addition of ship traffic due to the harbour expansion is not expected to have a significant visual intrusion and the impact can be classified as low negative to negligible.
- Visual impacts due to increased lighting and glare at night could increase as a result of increased activity and the number of ships that will be docking at the harbour. However, the visual effect is expected to be negligible to low (Volume F, Section 3.6).

In summary due to the current infrastructure both along the beach front and the current port, the proposed expansion will have limited impact on the sense of place.

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VOLUME I: PHYSICAL APPENDICES

APPENDIX 10.1

ATTACHMENT 2

OCEANOGRAPHY AND MARINE BIOLOGY

MARINE OUTFALL

Submitted to:

Dynatec Corporation

MARINE SPECIALIST STUDIES

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December 2005

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EXECUTIVE SUMMARY

BACKGROUND

This report details the findings and recommendations of specialist marine studies undertaken by Coastal & Environmental Services (CES) on behalf of Dynatec Corporation (Metallurgical Technologies Division) for the proposed marine outfall at Tamatave, which forms part of the overall Ambatovy Project, Madagascar. The study identifies potential impacts on the marine environment, in particular sensitive habitats such as coral reefs, related to the proposed project, with an indication of mitigations and recommendations.

PROJECT DESCRIPTION

The Ambatovy project is a large-tonnage nickel laterite project consisting of an open cast mine situated 130km from the capital Antananarivo, near Moramanga. The lifespan of the mine is estimated at 27 years. The first twenty years will consist of mining high grade ore, with the remainder spent mining lower grade ore. Annual production capacity is expected to total 60,000 tons of nickel and 5,600 tons of cobalt. The change in ore-grade is not expected to alter the marine outfall effluent characteristics or the volumes released into the ocean.

The ore extracted will be transported as slurry via a 195 km pipeline from Moramanga to the pressure acid leach (PAL) process plant near Tanakala, south of Tamatave (see Volume D, Figure 2.1-3). Subsequent to the extraction of the nickel and cobalt received via pipeline, the leached solids will be pumped to a neutralized tailings pond with wastewater from the plant. The location of the tailings area will be to the south west of Tamatave near Ambatomanoïna. The tailings area will offer an opportunity for the solids to settle and consolidate. Process plant water will contain magnesium, manganese, and sulphate in solution and low concentrations of other metals and high concentrations of suspended solids (see Volume D, Figure 2.1-3).

Prior to pumping to the tailings pond, the water is neutralized to pH 8 using calcium carbonate (Limestone), imported in large volumes for this project. At this pH most of the metals will be precipitated as solids thus removing iron, aluminium, nickel, cobalt, zinc, copper, chrome, the bulk of the manganese and a portion of the magnesium prior to discharge to tailings storage and dilution by rainfall.

Supernatant water, which will include rainwater, will be pumped from the tailings area back to the process plant where a portion of the water will be reused; the balance of this water will be disposed of to the ocean via an 700 mm outfall pipeline at an estimated 1 897 m³/hr. The pipeline will include a 100 m diffuser section at the end to promote rapid mixing (dilution) of the constituent elements. The effluent can be pumped out to sea at a maximum rate of 4000 m³ per hour. For this reason all the analyses and interpretations within this report have used this maximum scenario in the impact evaluations as a precautionary approach. Thus estimates may never achieve the anticipated responses or the eventual degree of impact.

Using the modelling information of PRDW, the length of pipeline in the sea will be approximately 975 m to attain a final depth of 20 meters. The location of the outfall has not yet been fixed, but will be located approximately 8 km south of the Tamatave Port and north of the Ivondro River mouth. The construction methodologies for the outfall pipeline have not been finalized, but recommendations will be made regarding accepted best practice methods.

The proposed project will result in a number of actions as a result of the open cast mining, slurry plant, establishment and operations of the tailings facility and PAL process plant.

Actions, which will directly affect the marine environment will include:

- construction and operation of a marine outfall pipeline;
- disposal of effluent containing suspended solids, metals and sulphate;
- alter water quality and sediment characteristics within a sacrificial zone; and
- placement of a significant structure, which may impact on local fisheries.

For the basis of this study PRDW was tasked to provide several scenarios based on various flow rates, wind and ocean current changes, for the marine specialists to analyze the resultant impacts of the effluent. This was in producing a sensitivity map of the region to summarize the possible impact of the proposed outfall (Chapter 3).

The modelling included plume dynamics (direction from source and vertical and horizontal mixing/dilution of effluent constituents) under the following scenarios:

- Varying lengths of outfall pipeline to achieve water depths of 10, 20 and 25 m.
- Varying diffuser arrangements at the end of the outfall.
- Varying discharge rates of 2 000, 3 000 and 4 000 m³/hr.
- Varying periods of calm (no wind and no current).
- Extreme conditions, such as cyclonic winds, waves and associated currents.

ENVIRONMENTAL DESCRIPTION

Tamatave lies on the east coast of Madagascar in the Province of Toamasina. A major feature of the region is the Port of Toamasina, which acts a major supply and export facility in the country. The coastline is exposed with sandy beaches and several estuaries are located in the immediate vicinity, e.g. the Ivondro to the south and Ivoloina to the north. None of the estuaries in the immediate vicinity have mangroves, with the nearest stands being located on the coast opposite Ile Sainte Marie (Anon. 2002). High annual rainfall of approximately 3000mm ensures a high level of freshwater input into the marine environment within the region. Due to farming and open-caste graphite mining

activities in catchment areas, the terrestrial sediment load during peak river flows in the Ivondro River is extremely high. As a result, turbidity in the nearshore zone is high, with plumes extending both longshore and offshore beyond the islands such as Nosy Faho and Ile Aux Prunes. Total suspended sediment loads estimated in the Pangalanes Canal, which connects with the Ivondro River and ultimately the sea, range between 3 and 860 mg/l. The majority of the sites however when averaged, had TSS values of 30 mg/l. It is anticipated that this value is higher in the nearshore environment due the cumulative effect of impacts of the Ivondro River catchment, kept in suspension by the wind and wave action, along the coastline.

The proposed outfall is located approximately 8 km south of Tamatave harbour on a straight section of coastline without any visible rock outcrops. The sandy bottom is gently sloping in depths exceeding 10 m with an average slope of approximately 1:30 from 10 m depths to the low water mark. The upper beach appeared steep with fairly coarse sediment indicative of a high energy surf zone. The dynamic nature of the nearshore zone and the frequent flooding of the Ivondro estuary were evidenced in the shifting of the estuary mouth from the position indicated on the nautical chart of 1972 to a site almost one nautical mile further south.

Sea temperatures from the RN Hydrographic Office (1990) indicate that average temperatures ranged between 24 and 28°C can be expected at Tamatave. During the site visit surface temperatures of 25°C were measured. Divers reported little changes in temperature with depth and a maximum difference of 2°C was estimated for temperatures at depths down to 30 m compared to the surface temperature.

According to RN Hydrographic Office (1990) the salinity of sea surface water can be expected to vary from 34.0 to 35.0 ppt in the Tamatave area. It also states that the surface water density can vary from 1022 kg/m³ to 1026.5 kg/m³, with maximum densities occurring in winter. Extreme winds occur in the form of cyclones that hit Madagascar on a regular basis. The maximum wind velocity that has been measured during a cyclone at Tamatave was 180 km/hour. A total of 64 cyclones passed within 500 km of Tamatave in the period 1961 to 1979, which gives an average of 3.5 per year. Of the cyclones occurring during this period 94% had a central pressure of 755 millibars or less.

Current measurements reported were measured from 1954 to 1956 at a number of locations on the inside of the harbour and at the head of the breakwater. In general currents were found to be weak at approximately 0.05 to 0.1 m/s, a fact confirmed in discussions with the harbour pilots.

The regional oceanography is of interest as Tamatave falls within a zone of current convergence. The southward flowing East Madagascar Current generates an offshore reverse current between it and Ile Sainte-Marie, and immediately to the south. Further to the south, the East Madagascar current generates inshore, northward-flowing reversal currents. Tamatave lies within the convergence of these two systems. In summer, the current regime results in low-grade upwelling south of Ile Sainte-Marie, further

contributing to the turbidity in the area. On a larger scale, offshore oceanic currents are highly variable, but are generally north to south.

No previous studies regarding sediment movement were available. Dredging records from the port indicate that sand moves in a southward direction that requires periodic maintenance dredging on the shoreward side of Mole A. According to Port authorities, no dredging has apparently been carried out at the head of the breakwater.

SENSITIVE HABITATS

Coral reefs are considered an invaluable natural asset. They are extremely productive ecosystems with a biodiversity value comparable to or greater than that of the Amazon Forest. They are important nursery and feeding grounds for edible fish, a source of natural products in the search for new pharmaceuticals and are prized by the ecotourism industry for diving ventures. Human activities such as dredging, dynamite fishing, coral mining and coastal development as well as the indirect consequences of human perturbation (global warming and crown-of-thorns starfish outbreaks) are endangering their existence. Recent estimates have indicated that they are currently diminishing by as much as 5% p.a. and international concern for their conservation is increasing. Catastrophic bleaching with far greater mortality followed an increase in sea temperature during the 1998 El Nino Southern Oscillation (ENSO).

Diving surveys allowed for several reefs to be described. Although corals are present at most reef sites, they range from stressed to severely degraded primarily due to high turbidity levels, but also as a result of cyclone damage, fishing activities and ENSO-related bleaching.

While many of the major fish groups were represented in the surveys, e.g. Chaetodontidae, Pomacentridae, Pomacanthidae, Mullidae and Labridae, some are more noticeable either by their absence or poor representation. These include the snappers (Lutjanidae), emperors (Lethrinidae), kingfishes (Carangidae), seabream (Sparidae), rockcods (Serranidae) and rubberlips (Haemulidae). The absence of many of these fish may well be due to the extreme fishing pressure at all the sites that were dived. Most of these species are the larger reef fish, which are susceptible to being captured and are prone to overexploitation. A report on environmental indicators in the Toamasina province stated that the absence of large predatory fish on reefs was identified as a key indicator of high fishing pressure.

There are few concerns related to marine impacts during the construction phase of the outfall, although the fishing industry should be informed of the timing of the project.

Near-field dilution modelling of the key effluent components demonstrated that water quality guidelines should be achieved in a depth of 20 m once the effluent reaches the surface. A dilution factor, which is independent of temperature, in excess of 25 was experienced for water depths between 10 and 20 m. The distance of the pipeline from

sensitive reef habitats means that risks due to smothering, turbidity and toxicity are low within the vicinity of sensitive systems such as Nosy Faho. The risk to the fishing industry is moderate due to a gillnet fishery within the outfall region. The risk to the tourist industry is low due to the distance offshore and rapid dilution.

The effective dilution of the effluent will result in most constituents being lower than the Madagascan water quality guidelines. The exceptions being Total Suspended Solids, Manganese and Sulphate. A review of ecotoxicological data, related to marine organisms, revealed little evidence that these concentrations of manganese or sulphate would be toxic. The TSS values would however impact on the sensitive coral reefs if the effluent plume would settle within these areas. The coral reef of Nosy Faho was of particular concern as this reef had the greatest variety of organisms.

CONCLUSIONS

The above study comprised a snapshot assessment of the nature and condition of the Tamatave reefs to establish whether the proposed marine disposal of effluent from the nickel processing plant is a viable option. A fatal flaw is unlikely, but further quantitative work is needed. The precautionary approach has thus been followed due to the lack of temporal, spatial coverage of accurate physical and chemical oceanographic data describing the site specific conditions.

Nevertheless, one can conclude that the Tamatave reefs are extensive but naturally stressed and are relatively poor in biodiversity. Their condition appears to have been further compromised by subsistence fishing activities, increased turbidity and ENSO-related coral bleaching in that order. With this in mind, the added effect of the marine outfall and associated effluent are likely to be minimal. However, the outfall should be located between *Recif du Sud* and *Nosy Faho* at a distance that would ensure minimal effect on both these reef systems so that further cumulative disturbance on these stressed reefs is avoided. According to the nearfield dilution modelling, effluent components are diluted to within water quality limits by the time they reach the water surface. As such, the proposed site is regarded as suitable at this stage. Consideration must also be given to the future improvement in the management of the reef resources in Madagascar in making the final assessment. Growing local and international concern over the loss of valuable coral reefs are bound to bring this about, particularly in view of local dependence on the marine resources. The effects of the pipeline must thus be minimised so that the poor condition of the reefs is not exacerbated, nor their future recovery compromised.

Specific conclusions arising from the nearfield dilution modelling are that an outfall extending 975 m from the high water mark and in 20 m water depth should provide sufficient dilution to meet environmental guideline values. The required dilution should be achieved by nearfield (turbulent) mixing, which will reduce sensitivity to current direction and velocity.

The commercial fishery (prawns and linefishery) as well as the small-scale commercial hand line fishery travel considerable distances to their fishing grounds both to the north and south of Tamatave. They therefore fish predominantly outside of the study area and away from the proposed outfall area in, which the effluent will be discharged. It is therefore very unlikely that these fisheries will be impacted by the discharge in anyway. The boats utilising the harbour, however, may suffer from interruptions to their usual routines during the construction phase of the pipeline.

Of the key fishing areas surrounding the Tamatave port and the proposed location of the pipeline, the areas utilised by the local traditional fishermen on a regular basis, situated closest to the proposed discharge location may be impacted as these fisheries are important and the local population is socially and economically dependent on these fisheries for their livelihoods.

Five possible issues were identified in the construction and operational phases of the proposed project in this assessment. These are listed as follows:

- Issue 1 - Specific impacts on the near shore environment – construction phase
- Issue 2 - The effects of the pipeline construction on fishing activities
- Issue 3 - Specific impacts on the near shore environment – operational phase
- Issue 4 - Impacts on the fisheries resource
- Issue 5 - Impact of the outfall on tourism

Two of these issues seem to be a replicate, but both have independent impacts with varying spatial and temporal scales, i.e. operational vs. construction phase and around the diffuser vs. distant reefs. The impact which could have the greatest significance would be the impact of the outfall on the biota.

During the construction phase impacts on the nearshore environment will include short-term disturbances of the marine biota, in particular the benthic (bottom living) organisms. These would be impacted on by physical disturbance such as the re-suspension of sediments. However, shortly after pipeline has been installed, the region would be re-colonised by biota. This impact may seem severe, but due to the turbid conditions that exist, most organisms including fish and benthic species, within the region are tolerant of disturbance and would return. Therefore the overall significance would thus be low. Similarly this would be evidenced within impacts relating to the fisheries. The disturbance of the benthic communities may impact on the food resources of fish species caught. Thus during construction the fish quotas caught may decrease. Due to the benthic species having the slowest recovery rate, post construction, this impact on the fishery may be moderate due to the time taken for fish resources to return.

The operational impacts could be seen as longer-term affects on the marine environment, with the most significant being the increase in turbidity and deposition of solids such as manganese and sulphate. The greatest area of impact would thus be an area where the effluent would not be sufficiently diluted for a period that would exceed the tolerance

limits of the majority of organisms. This area is termed a sacrificial zone or zone of influence around the diffuser, could be seen as the worst impacted. According to the results of PRDW, when the worst case was modelled, the zone could extend to a radius of between 500 m and 1000 m around the diffuser (Based on worst case scenario of maximum flow rate of 4000 m³/hour with no wind or current. The majority of the effluent within this area would have would persist for a short period at the maximum concentrations of the effluent before it was diluted. Beyond this zone of influence the dilution requirements as per the Madagascar Guidelines, would always be achieved and the degree of impact would be reduced to negligible proportions as the plume would have been diluted between to the 80 to 84 times before reaching the sensitive reef environment of Nosy Faho. Thus the effluent characteristics such as TSS and Manganese would have been diluted to 1.2 mg/l and 59 mg/l respectively. Based on the available baseline info for TSS within the region, thus would seem lower than the natural conditions and have a limited cumulative impact. Manganese in turn would be 80% below the Madagascar limits within the worst case scenario. Concentrations below this would however not persist longer than 6.9 hours. This time period is significant as most marine organisms would respond negatively to exposure for more than 48 hours, which is then not the case for the proposed project.

The ecosystems within the zone of influence around the outfall, were found to be poor and had no significant conservation value, thus the impact of the nearfield deposition of the outfall would have a low significance. Preliminary surveys showed only limited community assemblages of fish and a very low species abundances of benthic (bottom living) organisms, within this region.

In summation although the outfall would seem to pose a threat to the marine environment, the proposed design (975 m at 20 m deep), the current poor state of the reefs and fish communities and the high turbidities presently occurring, the outfall have a low significance.

Impacts which would have a moderate impact include the loss of benthic invertebrates, impact on fisheries and the possible impact of fishing vessels collision with the construction vessels. These are unlikely to occur if the region is properly managed.

The remainder of the impacts were rated as low if sufficiently mitigated.

RECOMMENDATIONS

Due to the majority of impacts being considered in the design of the outfall and captures in the modelling process, there are a limited number of mitigations.

In order to minimise the remaining negative impacts, which may arise as a result of the effluent discharge the following recommendations are made:

Pipeline Construction: The pipeline should be constructed using the float and lay method, as this would have the least impact on the environment. Due to the short length

of the pipeline, it further suggested that the pipeline could be constructed in an already impacted area and towed to the site via the sea, Pangalanes canal or the Ivondro River. This would also minimise the impact on the terrestrial environment and the need for a large construction area. This would in turn minimise the impact on the local inhabitants, fisheries and shipping. Construction on a solid substrate onshore, will also facilitate pressure testing before commissioning thereby reducing the needed for extended work periods on the seabed.

Public Awareness: Although all government representatives were familiar with the project, many of the traditional fishermen had heard of the Dynatec Project but were not familiar with the concept of the effluent discharge pipeline. These people are locally dependent on the marine resources and any potential impacts need to be communicated to them at an early stage to avoid confusion and negative perceptions regarding the project. Public engagement should be initiated, particularly with the communities south of the port.

Biological Monitoring: Several sites within the bay and on reefs should be monitored together with similar reference sites. Due to the rough seas, it is suggested that permanent quadrats be installed to reduce the risk of monitoring different site localities at each survey. It is further recommended that preliminary ecotoxicological work be initiated prior to construction and as part of an on-going programme. This will provide a better understanding of current baseline impacts against which the outfall influences can be measured. Specific sampling need not occur, but local fisherman could be engaged in collecting specimens or trained to collect tissue samples (livers or kidneys).

Water Quality Monitoring: Guidelines and possible target water quality criteria have been indicated in this report. This together with the current baseline surveys, will provide better background information on the region and provide a better means of measuring the effectiveness of management strategies in future.

Fisheries Monitoring: The traditional fisheries occurring in close proximity to the outfall location are the most significantly impacted by any negative effects of the effluent discharge. In order to ensure that impacts are identified at an early stage and mitigatory measures can be implemented a monitoring programme should be initiated which takes into account ecological health as well as changes in fishery dynamics.

CHAPTER 1. INTRODUCTION

1.1 INTRODUCTION

This report details the findings and recommendations of the marine specialist studies undertaken by Coastal & Environmental Services (CES) on behalf of Dynatec Corporation (Metallurgical Technologies Division) for the proposed marine outfall at Tamatave, Madagascar (Figure 1.1). A comprehensive environmental assessment is currently underway, as per a requirement of the Madagascar authorities, which will be supplemented to meet the Equator Principles, including various World Bank and IFC policies and guidelines that apply. Terms of reference for the work were developed in consultation with the government and include both environmental and social issues. This work is to be submitted to the Office National de l'Environnement (ONE) for review and approval.

The proposed outfall forms part the Ambatovy Laterite Project, which includes a process plant and tailings facility south of Tamatave. The town Tamatave is located at 18° 09.00 S, 49° 25.00 E on the NE coast of Madagascar in the Province of Toamasina (Figure 1.1).

The field investigations for the study were conducted in June 2004 and August 2005, which included SCUBA diving surveys of the coral reefs together with assessments of the fish populations and fisheries. Interviews were also conducted with the project engineers, Dynatec representatives, relevant government departments, Tamatave Port authorities, rural community representatives, fishermen, tourism operators and other interested and affected parties. Prestedge, Retief, Dresner & Wijnberg (PRDW) were approached by CES to conduct the modelling investigations of the plume dynamics and dilution of outfall effluent based on available oceanographic data. In addition, PRDW supplied specialist input with regards the design criteria of the outfall pipeline and diffuser arrangement. The information PRDW, provided was then integrated into the specialists' studies of the regional biota and ecosystems, which formed the basis of the impact assessment.

1.2 PROJECT DESCRIPTION

The Ambatovy project is a large-tonnage nickel laterite project consisting of an open cast mine situated 130 km from the capital Antananarivo, near Moramanga (Figure 1.1). The lifespan of the mine is estimated at 27 years. The first twenty years will consist of mining high grade ore, with the remainder spent mining lower grade ore. Annual production capacity is expected to total 60,000 tons of nickel and 5,600 tons of cobalt. The change in ore-grade is not expected to alter the marine outfall effluent characteristics or the volumes released into the ocean.

The ore extracted will be transported as slurry via a 195 km pipeline from Moramanga to the pressure acid leach (PAL) process plant near Tanakala, south of Tamatave (See Volume D, Figure 2.1-3). Subsequent to the extraction of the nickel and cobalt received via pipeline, the leached solids will be pumped to a neutralized tailings pond with wastewater from the plant. The location of the tailings area will be to the south west of Tamatave near Ambatomanoïna. The tailings area will offer an opportunity for the solids to settle and consolidate. Process plant water will contain magnesium, manganese, and sulphate in solution and low concentrations of other metals and high concentrations of suspended solids (See Volume D, Figure 2.1-3).

A portion of the water is reused in the plant to wash the residue solids and the remainder is mixed with leached solids from the last washing stage. Prior to pumping to the tailings pond, the water is neutralized to pH 8 using calcium carbonate (Limestone), imported in large volumes for this project. At this pH most of the metals will be precipitated as solids thus removing iron, aluminium, nickel, cobalt, zinc, copper, chrome, the bulk of the manganese and a portion of the magnesium prior to discharge to tailings storage and dilution by rainfall.

Supernatant water, which will include rainwater, will be pumped from the tailings area back to the process plant where a portion of the water will be reused; the balance of this water will be disposed of to the ocean via an 700 mm outfall pipeline at an estimated 1 897 m³/hr. The pipeline will include a 150 m diffuser section at the end to promote rapid mixing (dilution) of the constituent elements. The effluent can be pumped out to sea at a maximum rate of 4000 m³ per hour. A separate water basin will be constructed so that the supernatant pond volume in the tailings basin can be minimized. This will make the tailings basin more manageable while promoting air drying to achieve higher tailings density and greater physical strength. The water basin is for operational storage and containment, designed to accommodate 1:50 year storm events.

Using the modelling information of PRDW (Chapter 4) the length of pipeline in the sea will be approximately 975 m to attain a final depth of 20 meters. The location of the outfall has not yet been fixed, but will be located approximately 8 km south of the Tamatave Port and north of the Ivondro River mouth (Figure 1.1). The construction methodologies for the outfall pipeline have not been finalized, but recommendations will be made regarding accepted best practice methods (Volume F, Section 3.9).

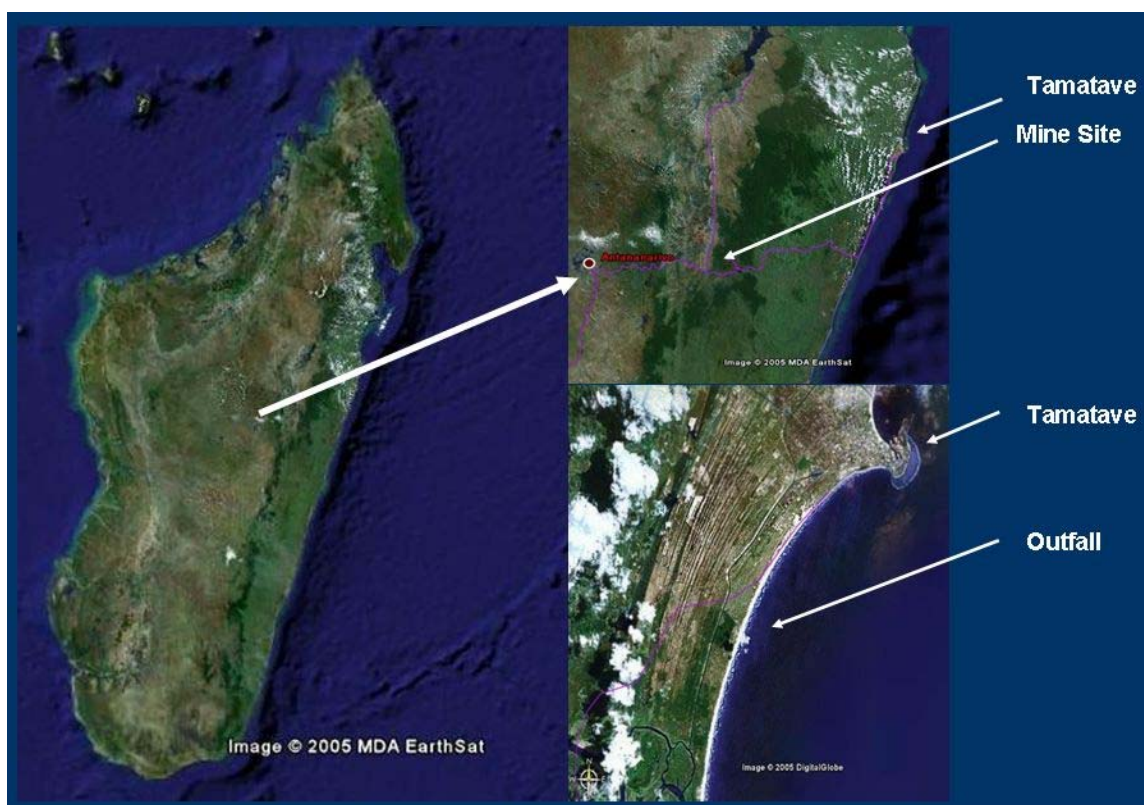


Figure 1.1: Locality of proposed mining area and the marine outfall pipeline.

The proposed project will result in a number of actions as a result of the open cast mining, slurry plant, establishment and operations of the tailings facility and PAL process plant.

Actions that will directly affect the marine environment will include:

- the construction and operation of a marine outfall pipeline;
- the disposal of effluent containing suspended solids, metals and sulphate;
- the alter water quality and sediment characteristics within a sacrificial zone; and
- the placement of a significant structure, which may impact on local fisheries.

1.3 STUDY RATIONALE

The outfall effluent constituent list provided by Dynatec was used as the basis of the modelling study and in the assessment of marine biological responses to the outfall. Dynatec after the onset of this study revisited this list on several occasions, to characterize the outfall composition and thereby allowing for the more accurate

assessment of the effluent's dispersion and final dilution. The modelling then aided the biological specialists to assess the long-term affects on the environment by the effluent based on known responses of organisms to various chemical concentrations. A critical evaluation of various international standards and guidelines for marine water quality (Table 1.1) was undertaken for this study. Although the Madagascan Water Quality Standards were used, World Bank and US-EPA guidelines were also used where certain constituents had no local guidelines. If the guidelines differed the lowest or most sensitive estimate was preferred as a precautionary approach.

For the basis of this study PRDW was tasked to provide several scenarios based on various flow rates, wind and ocean current changes, for the marine specialists to analyze the resultant impacts of the effluent. The modelling included plume dynamics (direction from source and vertical and horizontal mixing/dilution of effluent constituents) under the following scenarios:

- Varying lengths of outfall pipeline to achieve water depths of 10, 20 and 25 m.
- Varying diffuser arrangements at the end of the outfall.
- Varying discharge rates of 2 000, 3 000 and 4 000 m³/hr.
- Varying periods of calm (no wind and no current).
- Extreme conditions, such as cyclonic winds, waves and associated currents.

The possible impact of individual constituents within the outfall based on the dilution information, the water quality guidelines and any sensitive organisms identified by the specialists have been described in Volume E, Section 3.9. This information was then used as the basis of the impact evaluation also in Volume E, Section 3.9.

1.4. TERMS OF REFERENCE

CES were approached by Dynatec Corporation to conduct a specialist marine study on the possible affects of the proposed Ambatovy Project's marine outfall.

CES initiated the following specialist studies:

1.4.1 EFFLUENT PLUME AND SETTLING MODELS - PRDW

1. Accessed and reviewed relevant literature. This included the Ambatovy Nickel Project pre-feasibility report and the Océanide report on waves, wind and currents within the region.
2. Conducted near and far-field modelling of the tailings plume originating from the marine outfall. All modelling was done using US EPA approved software, e.g. the CORMIX model for far-field modelling.
3. Modelled the fate of any solids (fines) that would flow through the outfall.

4. Provided an estimate of the area, depth and location of the fines exiting the outfall.
5. Modelling included plume dynamics (direction from source and vertical and horizontal mixing/dilution of effluent constituents) under the following scenarios;
 - Varying lengths of outfall pipeline to achieve water depth of 10, 20 and 25 m.
 - Presence and absence of a diffuser system at the end of the outfall.
 - Varying discharge rates of 2 000, 3 000 and 4 000 m³/hr.
 - Varying periods of calm (no wind and no current).
 - Extreme conditions, such as cyclonic winds, waves and associated currents.
6. An indication of the limitations of the available data and modelling result was provided.
7. Provided an indication of the level of confidence in the modelling results.

Table 1.1: Water quality guidelines for South Africa, USA, UK and Australia (natural environment) used in the interpretations within this report

Parameter	Description	Madagascar Limit ¹	SA Guidelines (Natural Environment)	International Guidelines			Source
				USA	UK	Aus.	
PH		6 - 9	7.3 - 8.2	6.5 - 8.5	6.0 - 8.5		
Temperature		30					
TSS	Total Suspended Solids	60 mg/l					Madagascar
Element		Units - mg/l	Units µg/l	Units µg/l			
Al	Aluminium	5					
Sb	Antimony						
As	Arsenic	0.05	12	36	25	50	EEC (after UK)
Ba	Barium						
Be	Beryllium						
Bi	Bismuth						
B	Boron						
Cd	Cadmium	0.02	4	9	2.5	2	Australia
Ca	Calcium						
Cl	Chloride						
Co	Cobalt						
Cu	Copper		5	3	5	5	US-EPA (1 hr ave)
Cr _T	Chromium (total)	2	8	1	15	50	Australia
F	Fluoride		5 000				
Fe	Iron	0.5			1000		EEC (after UK)
Pb	Lead	0.2	12	6	25	5	Australia
Li	Lithium						
Mg	Magnesium						
Mn	Manganese	5					Madagascar
Hg	Mercury	0.005	0.3	0.3	0.1	5	Australia
Mo	Molybdenum						
Ni	Nickel	2	25	30	15	3	Australia
P	Phosphorus						
K	Potassium						
Sc	Scandium						
Ag	Silver		5		1	50	Australia
Na	Sodium						
Si	Silicon						

Table 1.1: Water quality guidelines for South Africa, USA, UK and Australia (natural environment) used in the interpretations within this report (continued)

Parameter	Description	Madagascar Limit ¹	SA Guidelines (Natural Environment)	International Guidelines			Source
				USA	UK	Aus.	
Sr	Strontium						
S _T	Sulphur (total)						
S(SO ₄)	Sulphate (sulphate)	83				15	Madagascar
Te	Tellurium						
Tl	Thallium						
Sn	Tin			10			
Ti	Titanium						
W	Tungsten						
U	Uranium						
V	Vanadium			100			
Y	Yttrium						
Zn	Zinc	0.5	25	40	50	none	EEC (after UK)
Zr	Zirconium						

Deliverables

The specialist report included all modelling results and demonstrated the efficacy of the proposed outfall design with regards to the dilution requirements of the effluent components.

1.4.2 CORAL REEF SURVEY - ORI (OCEANOGRAPHIC RESEARCH INSTITUTE)

Professor Michael Schleyer from ORI, with the assistance of Dr Jean Maharavo from Aquaterre conducted the coral survey. Dr Maharavo was also be responsible for the fish survey. Dr Louis Celliers and Mr Angus Macdonald from ORI will assisted with the data analysis. Ms. Naomi Richardson accompanied the team to Madagascar as translator and facilitated any local transactions and interviews.

The following TOR were satisfied for this specialist study:

1. Accessed and reviewed the relevant literature.
2. Conducted a diving survey to reaffirm the findings detailed in the pre-feasibility report and undertook quantitative assessments of the coral reefs in the area. Professor Schleyer lead this survey with local knowledge and input provided by Dr Maharavo.
3. Quantitative assessments refer to the corals only, as the time frame did not allow for a truly quantitative assessment of fish communities.
4. Survey ensured complete coverage of all representative reef types (bio-zones) in the area. A minimum requirement was to revisit all the sites dived during the pre-feasibility phase and then to conduct additional dives at locations on the seaward side of Ile Aux Prunes (2 dives), Banc des Six Mètres (1 dive), Le Grande Recif (2 dives), Nosy Faho (2 dives) and the islands further south, namely Nosy Dombala and Nosy Fonga (1 dive at each island). This is totalled 18 dives, which required a minimum of 9 days to complete under the conditions.

5. In order to assess the corals, transects were photographed with a digital camera when conditions permitted, and these were analysed in detail for species richness, biodiversity, % coverage and overall health or condition.
6. Diving surveys to assess the fish communities associated with the coral reefs were conducted at the same time as the coral dives. Although overall biodiversity was assessed, particular attention was paid to indicator species that could be related to reef health.
7. Professor Schleyer was in overall charge of diving operations and coordinated daily activities in this regard.
8. AQUATERRE provided all logistical support and planning with respect to diving equipment.
9. Dr Louis Celliers and Mr Angus Macdonald assisted Prof. Schleyer in the data analysis (digital image analysis, species identification etc.).

Deliverables

1. Professor Schleyer produced a specialist report detailing the following.
 - Place Madagascar reefs in context in terms of corals. Rate importance of coral reefs in the Tamatave area in terms of regional and Global importance.
 - List major threats to corals and focus on susceptibility to contaminants that would be present in effluent discharge.
 - Description and location of dive sites.
 - Species diversity and richness.
 - Percentage cover.
 - Presence of other cover, e.g. soft corals, sponges etc.
 - Health of the reef and degree of damage.
 - Causes of damage, e.g. natural (storm and bleaching) or due to human activities (fishing net, anchors etc.).
 - Comment on risk of exposure or damage due to outfall pipeline based on diffusion modelling results produced by PRDCW.
2. Dr. Maharavo to produced a report on fish communities detailing the following;
 - Description of fish community at each dive site based on visual observations.
 - Relative abundance of major fish groups between and within sites.
 - Assessment of fish community in relation to reef type, e.g. coral cover, degree of damage, fishing pressure etc.
3. Aspects that may be duplicated in each report, e.g. dive site location and description should be combined. Prof. Schleyer and Dr. Maharavo to liaise with regards to the specifics.

Limitations and constraints

1. Diving surveys ideally need to be conducted when diving conditions are favourable. This means good visibility and relatively calm to moderate sea conditions with little or no wind. August is not considered a favourable month, and poor conditions seriously hampered activities.
2. Bad conditions resulted in poor coverage due to insufficient dives, inaccessibility to sites due to rough seas and inability to survey the reef and fish due to bad visibility.
3. The team spent 12 days on site and only performed diving operations when the conditions were deemed safe.

1.4.3 FISH AND FISHERIES SURVEY

Mr Russell Chalmers from CES with the assistance of Ms. Naiomi Richardson were responsible for the fisheries study:

1. The following TOR for this specialist study were achieved:
2. Reviewed the fishery survey in pre-feasibility report.
3. Provided an overview of all forms of living resource utilisation in the surrounding area, including the nearby islands and the Pangalanes Canal.
4. Provided an overview of the extent of harbour is utilization by trawlers and long liners from Madagascar and foreign countries.
5. Established the dominant user groups, classification (subsistence, artisanal, commercial, recreational), methods (nets, hook & line, spearfishing, baskets & traps, etc.), markets and economic importance.
6. Determined all resources utilised, e.g. fish, turtles, corals, octopus, shells etc. Which are most heavily exploited and which are in a state of decline.
7. Conducted interviews where possible. Boat owners/operators, government officials (environmental affairs or Department of Fisheries representative) factory or processing plant (e.g. Réfrigépêche) representatives, villagers (elders and fishers) and vendors who sell seafood [products in the market place were included. Obtained information about the dynamics of the fishery, e.g. conflict between groups, state of the resource, opinions on how the marine outfall will affect fishing activities and catches.
8. Determined if intended line fish fishery in the area, which includes the site of the marine outfall, has been initiated (see pre-feasibility report for details).
9. Ms Richardson acted as a facilitator and translator during all interactions and interviews with fishers or representatives of the fishing community/industry.

Deliverables

1. Mr. Chalmers will produce a specialist report detailing all aspects referred to in the TOR above.
2. The report also included a site map indicating areas that are heavily fished and the user groups involved.

Limitations and constraints

1. Access to some of the fishing sites, e.g. Nose Faho were hampered by poor weather conditions.
2. Interviews with government officials and senior representatives of the fishing industry were set up once the team was on site, which was on their availability and willingness to participate.

This study deals only with issues affecting the marine environment and marine habitats. Issues were regarded as either a risk (negative impact) or an opportunity (positive impact). A severity ranking is provided based on a subjective assessment of their overall impact. Similarly, a ranking of significance for each impact and a measure of confidence (certainty) are included. Based on these assessments, recommendations are made to Dynatec regarding the options available to them, and the environmental risks associated with each of them.

1.5 STRUCTURE OF REPORT

Chapter 1 provides a brief introduction to the marine study, a description of the proposed activities, the rationale behind the study, the terms of reference, the structure of the report and the project team members.

Chapter 2 details the approach, methodology and evaluation criteria used in this study. In addition, aspects relating to marine outfalls with regard their use, best practise and world standards are presented in this chapter.

Chapter 3 provides an environmental description of the area, and includes aspects of the marine ecology and marine processes.

Chapter 4 details the results of the PRDW modelling study used as the basis of the impact assessment in this report.

Chapter 5 is a list of references used in the report.

Chapter 6 provides the four appendices:

- Appendix 1 – Malagasy National Policy of the Environment (PNE).
- Appendix 2 – Elements of the 1996 Protocol to the London Convention.
- Appendix 3 – Details of authority and IAP liaison.
- Appendix 4 – Additional PRDW tables and diagrams, of the modelling studies.

The impact assessment, and methods used in the assessment, are provided in Volume E, Section 3.9.

1.6 MARINE ENVIRONMENT STUDY TEAM

1.6.1 PRE-FEASIBILITY TEAM

The pre-feasibility study team was made up of Dr Angus Paterson from CES, Dr. Aidan Wood from Gleneagles Environmental Consulting (GEC), Prof. Michael Schleyer of the Oceanographic Research Institute (ORI), Mr. Anton Holtzhausen and Mr. Jo Dresner from PRDW, Ms. Naomi Richardson from Rhodes University and Mr. Richard Andrianasolonanahary from Dynatec.

Dr. Paterson was the project leader, reviewer and the primary liaison between CES and Dynatec. In addition he provided logistical and administrative backup.

Dr. Wood was the project manager and was responsible for the coordination of the research team and the production of the prefeasibility report. He provided specialist input pertaining to aspects of the marine ecology of the site and consulted with authorities and other interest groups affected by the proposed activities.

Prof Schleyer provided specialist input into the aspects of coral reef description and health and was largely responsible for the sensitivity assessment of the immediate area around the Tamatave.

Mr. Holtzhausen provided specialist input into the marine processes associated with the marine outfall and was responsible for the modelling of the outfall plume which was used to assess the impacts on nearby marine habitats. Mr. Dresner was involved with reviewing the PRDW report with specific input into the preliminary design premise. He is also responsible for co-ordinating the dilution and plume modelling.

Ms. Naomi Richardson acted as translator and facilitated many of the interviews and business transactions that were conducted.

Mr. Richard Andrianasolonanahary was the Malagasy translator and assisted with facilitating all community engagements and interviews.

1.6.2 ENVIRONMETAL ASSESSMENT PHASE STUDY TEAM

The specialist fisheries assessment was undertaken during the same period as the specialist coral reef survey and the study team was comprised of the following persons: Mr. Russell Chalmers (CES), Ms. Naomi Richardson (Rhodes University), Prof. Michael Schleyer (ORI), Dr. Jean Maharavo (Local Fish Expert) and Mr. Richard Andrianasolonanahary (Dynatec), Dr. Brian Colloty (CES) & Dr. Angus Paterson (CES).

Dr. Brian Colloty was the overall project leader who was responsible for primary liaison with the client and review of the specialist reports. Dr. Paterson was responsible for the final review of the report.

Mr. Russell Chalmers undertook the fisheries specialist study and conducted all interviews with the assistance of Ms. Naomi Richardson. He obtained the relevant field information during site visits and prepared the overall fisheries study.

Ms. Naomi Richardson was the translator for all interviews and assisted with coordination and liaison with all stakeholders as well as assisted in preparing the report.

Prof. Michael Schleyer was responsible for the coral reef surveys, with the assistance of Dr Maharavo. Prof. Schleyer was also present during some interviews with key stakeholders when conducting the fisheries survey.

Mr. Richard Andrianasolonanahary was the Malagasy translator and assisted with facilitating all community engagements and interviews.

CHAPTER 2. STUDY METHODOLOGY

2.1 LITERATURE REVIEW

Background documents and information was obtained from various sources within Dynatec and Murray & Roberts. Additional information was obtained while in Tamatave, specifically from port authorities and Service d' Appui à la Gestion de l'Environnement (SAGE) pertaining to oceanographic data, environmental indicators in the Toamasina Province, a State of the Environment report for the Province and copies of the Constitution, environmental legislation and Codes of Best Practice. Information on marine outfalls and codes of best practice regarding their use was obtained from peer reviewed literature and the internet.

There does not appear to be any current legislation or policy that provides specific guidance with respect to the development of a marine effluent pipelines in Madagascar. However, the existing Malagasy National Policy of the Environment (PNE) does provide a broad framework with respect to environment principles (Appendix 1). Failing the existence of specific Malagasy policy, guidance with respect to the likely scenario for developing a marine outfall pipeline can be taken from current international trends, and policy developments in other counties such as South Africa, United Kingdom and Australia.

Internationally, the use of marine outfall pipelines is generally not a favored means of disposing of land-generated waste. This trend is reflected in two agreements, namely:

- Convention on the prevention of marine pollution by dumping of wastes and other matter, 1972 (widely referred to as the London Convention).
- 1996 Protocol to the Convention on the prevention of marine pollution by dumping of wastes and other matter, 1972, and resolutions adopted by the special meeting.

It is not known whether Madagascar is a signatory to either the Convention or the Protocol, however, some of the elements of the Protocol that might be relevant to any proposal to construct an outfall are detailed in Appendix 2. Should the Madagascar authorities be guided by the Protocol, it is foreseeable that the proponent of the pipeline will need to comply with the requirements of the Protocol at their expense. It should be noted that other developing countries, such as South Africa, have been guided by the Protocol requirements in establishing related policies. Thus the principles described in Appendix 2 may provide some indication of the likely scenario with respect to seeking authorization for developing a marine pipeline in Madagascar.

The Department of Water Affairs and Forestry (DWAF) in South Africa is currently in the process of developing a policy (DWAF Operational Policy) that will guide the future authorization and permitting of marine outfall pipelines. The Policy development process

has been significantly informed by international conventions and protocols and principles relevant to the European Union, USA and other countries. The requirements of the DWAF Operational Policy (see below) could be used as a useful benchmark with which to judge the possible regulatory approach that the Madagascar government might adopt when considering a pipeline proposal.

DWAF Operational Policy for the Treatment and Disposal of Land-derived Wastewater in Coastal Areas.

The following broad principles are applicable:

1. Pollution Prevention and Waste Minimization
2. Risk-aversion and Precautionary Approach
3. Receiving Water Quality Objectives Approach
4. Integrated Assessment Approach
5. Polluter Pays Principle
6. Participatory Approach

Proposed ground rules

The following ground rules selected from the overall policy are proposed, being relevant to Madagascar. It should be noted that the implementation of the ground rules would be very onerous for the development of a pipeline and could have significant cost implications. Ground rules 13 to 17, pertaining to Urban/Municipal Wastewater, have been excluded as they are not relevant. Ground Rule number 8 under Sensitive Areas is particularly relevant.

	Ground Rule
	Local Management Institutions
1	Disposal of land-derived wastewater to the marine environment (offshore, surf zone or estuaries) needs to be managed within the jurisdiction of a local institution, representing all the role players in a designated area. These can include existing institutions, such as pipeline forums, water quality committees or catchment forums.
	Legislative Framework
2	Disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process needs to be licensed. Also, a person who uses water must return any seepage, run-off or water containing waste which emanates from that use, to the water resource from which the water was taken, <u>unless the responsible authority directs otherwise</u> or the relevant authorization provides otherwise. (Integrated assessment approach).
3	The disposal of land-derived wastewater to the marine environment is subject to and Environmental Impact Assessment (EIA). (Integrated assessment approach).
4	A license issued for a water use, including the disposal of land derived waste-water, to the marine environment, is subject to a review every 5 years. Revisions can also be motivated on the grounds of negative impact to the environment and non-compliance to the license conditions. (Integrated assessment approach).
	Sensitive Areas
6	Discharges of land-derived wastewater to estuaries should not be considered.
7	Discharges of land-derived wastewater to the surf zone are to be avoided.
8	Discharges of land-derived wastewater to the off-shore marine waters through a marine outfall may be considered as an option provided that the suitability of the areas to accommodate such activities is properly assessed (Risk-aversion and precautionary approach).

9	Discharges of land-derived wastewater to Marine Protected Areas, is prohibited.
	Environmental Quality Objectives
10	Site-specific environmental quality objectives for the marine environment (excluding estuaries) must take into account the Madagascan Water Quality Guidelines for coastal waters or any future updates thereof (Receiving water quality objectives approach).
11	Quality objectives of existing discharges to estuaries.
12	As a rule, environmental quality objectives need to be complied with beyond the initial mixing zone (Risk-aversion and precautionary approach).
	Industrial Wastewater
18	The following is classified as “industrial wastewater”, requiring a license for disposal to the marine environment: <ul style="list-style-type: none"> - Water used in an industrial process on land. - Storm water runoff originating from industrial premises on land. - Freshwater or seawater used as cooling water on land. Seawater used in an industrial process on land, e.g. seafood processing and coastal mining activities.
19	An industry, discharging to a wastewater treatment works (WWTW) or directly to the marine environment (or whether applying for a license to do so) will be required to provide a detailed description of the waste stream both in terms of volume (quantity) and quality (i.e. listing all substances present and their concentrations and loads). (Pollution prevention and waste minimization, Risk aversion and precautionary approach).
21	List I substances are regarded as being particularly dangerous because of their toxicity, persistence and bioaccumulation. Pollution by List I substances must be eliminated (Pollution prevention and waste minimization). They include, Mercury, Cadmium, Poly-aromatic hydrocarbons, Organohalogens, Organophosphorus, and carcinogens, mutagenics, etc.
22	List II substances are considered less dangerous but nevertheless have a deleterious effect on the aquatic environment. Pollution by List II substances must be controlled and reduced (Pollution prevention and waste minimization). They include: Metalloids and metals and their compounds, cyanides, fluorides, pathogens, crude oils, biocides, etc.
	Scientific and Engineering Assessment
26	Where disposal of land-derived waste water to the marine environment is considered, a holistic process must be followed where potential impacts on the receiving environment is investigated both in the near and farfield (i.e. an ecosystem based approach) and where existing waste inputs or other anthropogenic activities in the receiving environment is taken into account so as to address the synergistic/cumulative interactions (Integrated assessment approach).
27	Marine disposal will only be considered where a discharge system is designed in accordance with recognized scientific, hydraulic and structural guidelines in order to meet environmental quality objectives. (Risk aversion and precautionary approach).
28	It will be expected that recognized numerical modelling techniques be applied in the design and assessment of a marine outfall (Risk aversion and precautionary approach).
29	A precautionary approach must be followed in the design and assessment of any wastewater disposal practice (to the offshore, surf zone or estuaries) where the temporal and spatial coverage and accuracy of physical and chemical oceanographic data do not adequately describe site-specific conditions (Risk aversion and precautionary approach).
	Monitoring and Contingency Plans and Implications
30	Any authority or industry responsible for the operation and management of a marine disposal system will be subject to the implementation of a monitoring programme (Pollution prevention and waste minimization; Integrated assessment approach; Participatory approach).
31	Authorities operating WWTW that receive industrial wastewater (trade effluents) shall ensure that monitoring programmes are implemented to record the individual flow and composition of such waste

	streams prior to entering the WWTW, as part of their industrial wastewater plan (Pollution prevention and waste minimization; Integrated assessment approach; Participatory approach).
32	Any authority or industry responsible for the operation of a marine disposal system will be required to prepare contingency plans pertaining to failure in operations or disasters (Pollution prevention and waste minimization; Integrated assessment approach; Participatory approach).
33	Any authority or industry responsible for the operation of a marine disposal system will be required to provide the DWAF with regular assessment on the performance of the marine disposal system (Pollution prevention and waste minimization; Integrated assessment approach; Participatory approach).
34	Where performance assessments indicate non-compliance to pre-determined specifications (including the environmental quality objectives), the responsible authority or industry will be required to propose mitigating actions to ensure compliance (e.g. rehabilitation). The responsible authority and industry operating the wastewater disposal system will be required to implement such actions at their own cost upon approval by the DWAF (Pollution prevention and waste minimization).

The central issue with respect to the disposal of wastes via marine outfall pipelines is the quality of the original effluent streams and the resultant impact on the quality of the receiving environment after dilution in the sacrificial mixing zone of the pipeline discharge point. The ultimate goal in marine water quality management is to keep the marine environment suitable for all designated uses. To achieve this goal, the objectives set for a particular marine environment should be based on the water quality requirements of designated uses (beneficial uses) in that particular area. The following are defined as beneficial uses of marine waters:

- Recreation;
- Mariculture (including collection of seafood); and
- Industrial uses (e.g. taking in cooling water and water for fish processing).

The natural environment or marine ecosystems, also require a certain water quality. As a rule of thumb, the water quality requirements of the natural environment need to be adhered to throughout, except in the 'sacrificial zones' that, at times, may be allocated to particular pollution sources.

2.2 FIELD TECHNIQUES AND SPECIALIST INPUT

Site visits were conducted in June 2004 and August 2005, where representatives from Regional government, the Port of Toamasina, the Regional environmental agency, the major fishing company (also major processor and distributor) and local communities were consulted regarding the proposed development. In addition to the interviews, diving surveys were conducted on both visits, with the inclusion of a fish and fisheries survey during the 2005 survey. Detailed methods are discussed in the relevant specialist sections.

2.3 IAP LIAISON (SEE APPENDIX 3)

A brief appointment with the Minister of the Interior, Mdme Edwige Soavamoma, whose portfolio includes Provincial environmental affairs, revealed her department was aware of the planned harbour expansion but not of the proposed outfall. We explained why we were in Tamatave and the reason and location for the outfall. The Minister suggested we speak with the regional SAGE representative regarding environmental issues.

We were unable to secure an appointment to see the Provincial Premier, but a letter of introduction was left with his personal assistant for his attention.

The meeting with the Regional environmental coordinator, Dr. William Rakotoarinivo from Service d'Appui à la Gestion de l'Environnement (SAGE), proved to be most helpful. He was aware of the proposed activities and has already been involved with Dynatec regarding the project. Mr. Rakotoarinivo provided documentation dealing with issues such as fauna and flora surveys, environmental legislation and codes of practice. He holds a doctorate in oceanography and provided some insight as to local conditions, current regimes and sources of turbidity.

An elder from the village of Tanakala located near the proposed outfall site close to the Evondro estuary mouth was informed of the proposed activities and interviewed with regards local fishing activities (Photo Plate 2.1).



Photo Plate 2.1: Interacting with local villagers at Tanakala near the Evondro estuary mouth.

The proprietor of the Eden tourist camp located in Tanakala on the banks of the Pangalanes Canal was informed of the project and asked about tourist activity in the area – this included information on seasonal activity and use of areas such as the canal and adjacent beaches.

The director general of Réfrigépêche, the major fishing company in the port was approached and informed of the project. In addition, he provided information on fishing activities in the region and expressed his interest at being kept informed of all developments relating to the outfall in particular.

2.4 LIMITATIONS

Due to the nature of the study, all issues that have been identified based on limited historical and / or short-term data. The paucity of data on the marine processes and habitats in the region has nevertheless, been supplemented with specialist knowledge in consultation with authorities, public interest groups and the wide body of international literature, which exists. The diving surveys and collection of oceanographic data (specifically currents and depth) was severely hampered by adverse weather conditions (winds and large seas) and poor visibility (characteristically 0.5 to 2 m). Detailed public and IAP interviews were not part of the TOR and were not held.

CHAPTER 3. ENVIRONMENTAL DESCRIPTION

3.1 STUDY AREA

Tamatave lies on the east coast of Madagascar in the Province of Toamasina. A major feature of the region is the Port of Toamasina, which acts a major supply and export facility in the country. The coastline is exposed with sandy beaches and several estuaries are located in the immediate vicinity, e.g. the Ivondro to the south and Ivoloina to the north. None of the estuaries in the immediate vicinity have mangroves, with the nearest stands being located on the coast opposite Ile Sainte Marie (Anon. 2002). High annual rainfall of approximately 3000 mm ensures a high level of freshwater input into the marine environment within the region. Due to farming and open-caste graphite mining activities in catchment areas, the terrestrial sediment load during peak river flows in the Ivondro River is extremely high. As a result, turbidity in the nearshore zone is high, with plumes extending both longshore and offshore beyond the islands such as Nosy Faho and Ile Aux Prunes. November to March also represents the cyclone season, and sea conditions during this period can be extreme. The CES surveys took place towards the end of the cyclone season, yet winter southerly winds ensured that sea conditions were still severe. Turbidity levels were high, and while no specific measurements could be taken, poor visibility at all dive sites and visual observations of the nearshore zone at the Ivondro estuary mouth and proposed outfall site (Photo Plates 3.1 and 3.2) were testament to the naturally occurring high sediment load in the marine environment, a mostly year round phenomenon.



Photo Plate 3.1: High turbidity levels in the nearshore zone at the Ivondro estuary mouth.

The proposed outfall is located approximately 8 km south of Tamatave harbour on a straight section of coastline without any visible rock outcrops. The sandy bottom is gently sloping in depths exceeding 10 m with an average slope of approximately 1:30 from 10 m depths to the low water mark. The upper beach appeared steep with fairly coarse sediment indicative of a high energy surf zone. The dynamic nature of the nearshore zone and the frequent flooding of the Ivondro estuary were evidenced in the shifting of the estuary mouth from the position indicated on the nautical chart (Hydrographique et Océanographique de la Marine 1972, chart 6319) to a site almost one nautical mile further south.



Photo Plate 3.2: High turbidity levels in the nearshore zone at the proposed location for the marine outfall.

Sea temperatures from the RN Hydrographic Office (1990) are shown in Figure 3.1 indicating that average temperatures between 24 and 28 °C can be expected at Tamatave. During the site visit surface temperatures of 25 °C were measured. Divers reported little changes in temperature with depth and a maximum difference of 2 °C was estimated for temperatures at depths down to 30 m compared to the surface temperature.

According to RN Hydrographic Office (1990) the salinity of sea surface water can be expected to vary from 34.0 to 35.0 in the Tamatave area. It also states that the surface water density can vary from 1022 kg/m³ to 1026.5 kg/m³, with maximum densities occurring in winter.

Tide levels for Tamatave were obtained from naval charts relative to Chart Datum (CD; Table 3.1).

Table 3.1: Tide levels for Tamatave.

Tide	Level (m CD)
Mean High Water Spring	+0.91
Mean High Water Neaps	+0.73
Mean Level	+0.59
Mean Low Water Neaps	+0.46
Mean Low Water Springs	+0.27

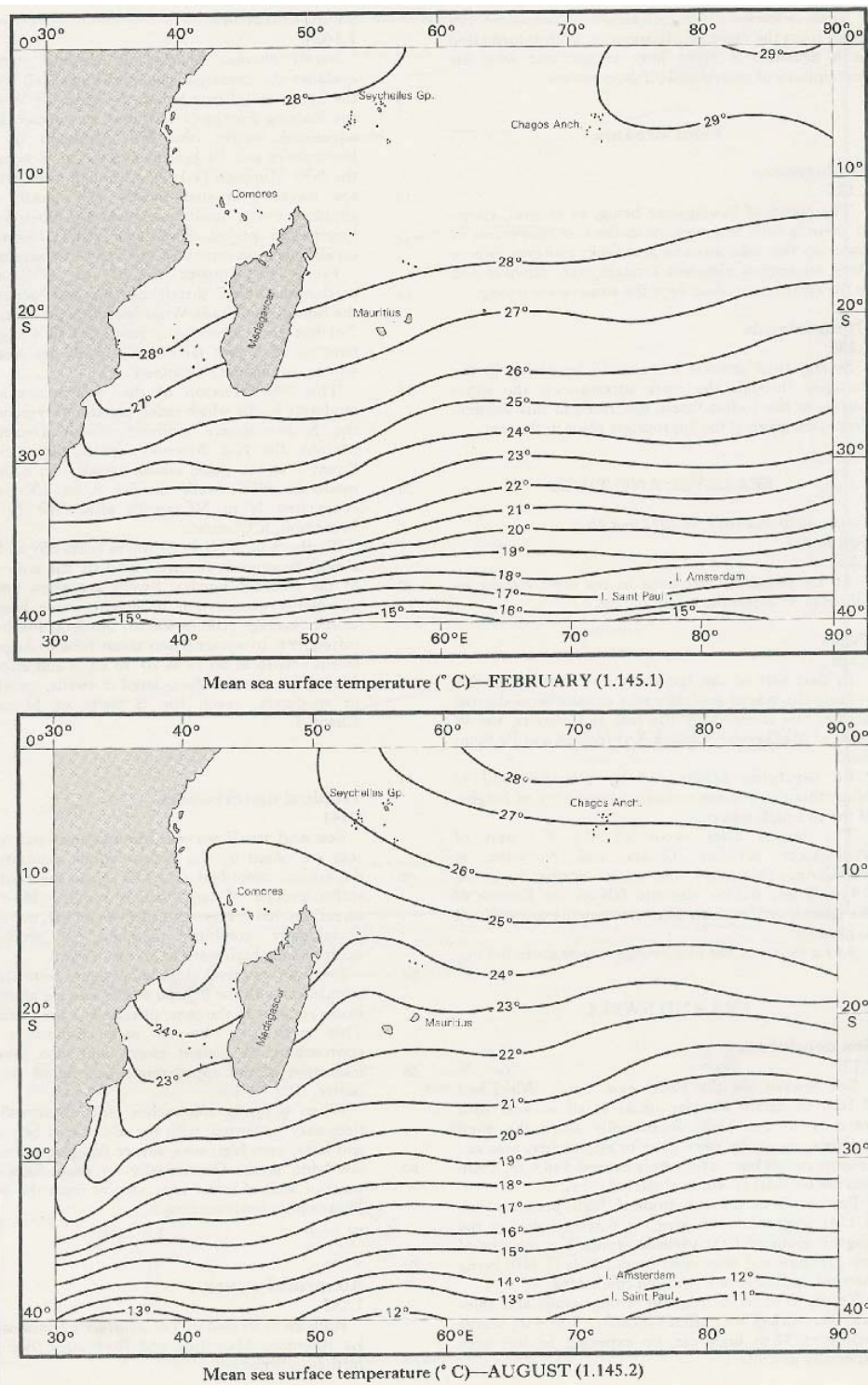


Figure 3.1: Mean sea surface temperatures (South Indian Ocean Plot).

WXTIDE (2000) was used for calculating predicted tidal values. A check on the time of sunrise and sunset confirmed that the correct time zone was reported by the software. Tidal measurements were carried out as part of a coastal engineering investigation (BCEOM and DHI, 1986) and predictions are therefore expected to be accurate.

An offshore wave rose based on VOS data from 1962 to 1975 is shown in Figure 3.2. These data indicate that offshore waves are predominantly from an easterly direction. This information is of general interest and not considered as accurate as specific measurements. Waves were measured at a location approximately two km south east of the breakwater head as indicated in Figure 3.3 (BCEOM and DHI, 1986). This measurement covered a two year period from September 1954 to August 1956 with only one 18 minute recording per day. Data are shown graphically in Figures 3.4 and 3.5. The graphs of significant wave height were digitised and sorted in order to establish wave heights for given return periods. This is summarised in Table 3.2.

Table 3.2: Return period significant wave heights.

Return Period	% Exceedence	Hs (m)
2 years	0.14	6.0
1 year	0.29	3.5
6 months	0.56	3.0
1 month	3.33	2.3
1 week	12.9	1.8

The average significant wave height of the measurements was 1.4 m. Peak wave periods ranged from approximately 7 to 15 s and directions from SSE to NE. It should be noted that these data relate to actual measured wave heights. ZLH (2004) obtained offshore wave data for 2003 from an NCEP model. The data consists of significant wave height, peak wave period and peak wave direction at three hourly intervals. These data show the same trends as the VOS data and those reported in BCEOM and DHI (1986). The maximum wave height extracted from the model had a southerly direction with a significant wave height of approximately 4.75 m and a peak period of approximately 14 s. Extreme design conditions at Tamatave relate to cyclones and significant wave heights of up to approximately 11 m can be expected for a 1:100 year return period (BCEOM and DHI, 1986). Such a design wave can be expected to have a wave period of 18 s. Since the deep sea direction could be normal to the coast it is recommended that the wave height be assumed to be unaffected by refraction for preliminary design purposes. The maximum wave height (Hmax) that could be expected would therefore be up to 20 m, subject to depth limitation causing breaking.

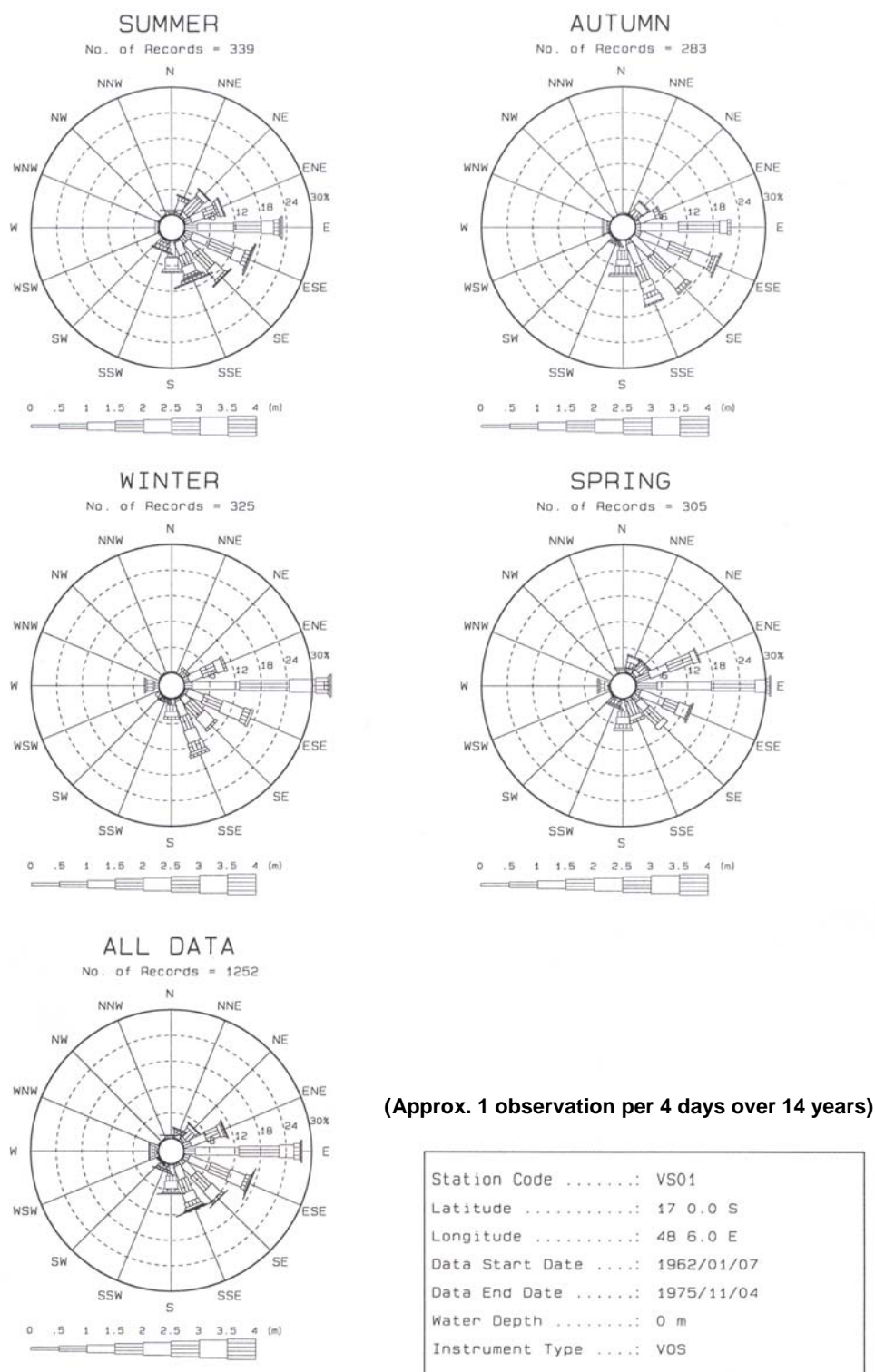


Figure 3.2: VOS wave roses – seasonal as well as all data combined.

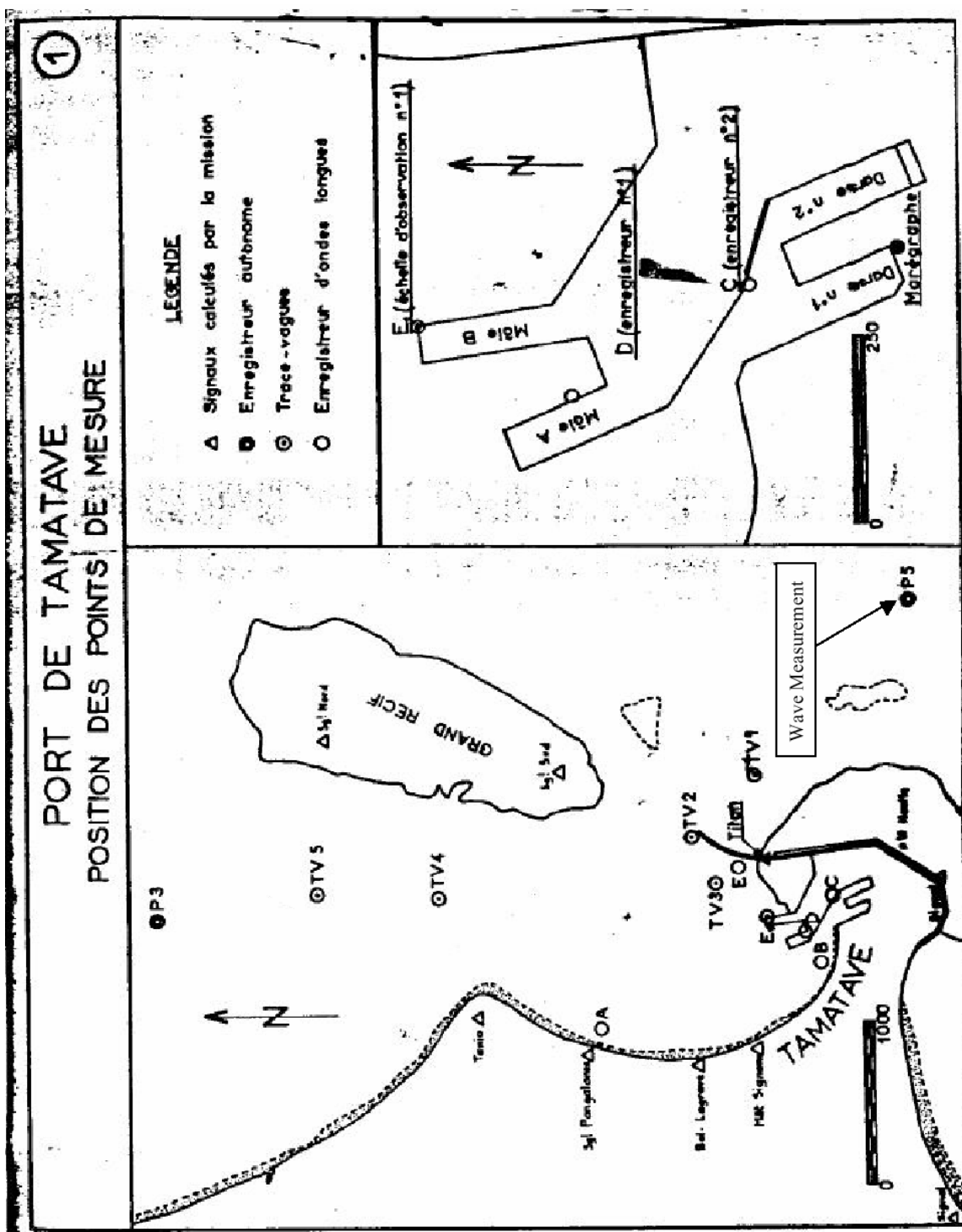


Figure 3.3: Wave measurement locations (BCEOM) and DHI, 1986).

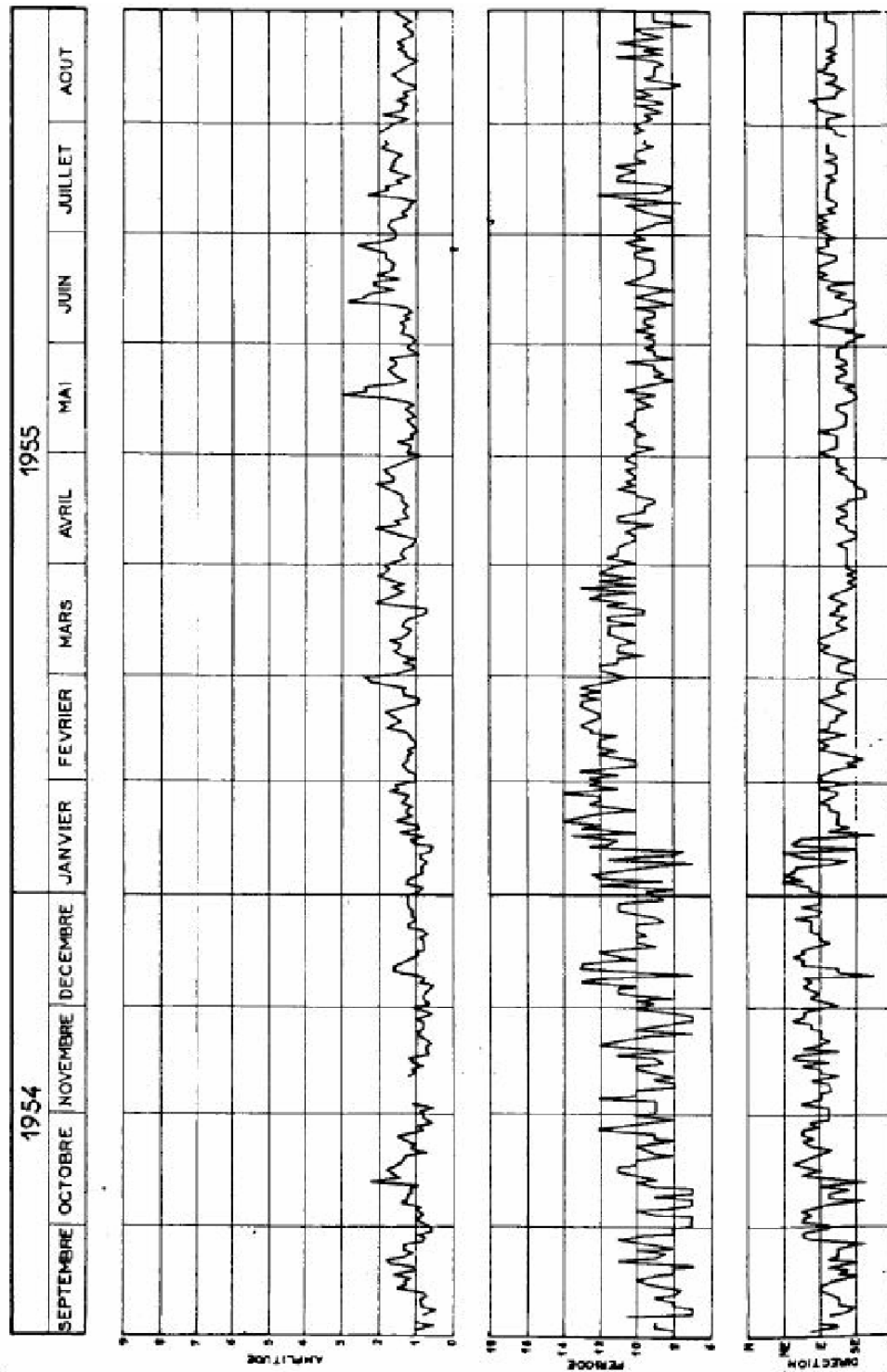


Figure 3.4: Graphic representation of directional wave measurements (BCEOM and DHI, 1954 & 1955).

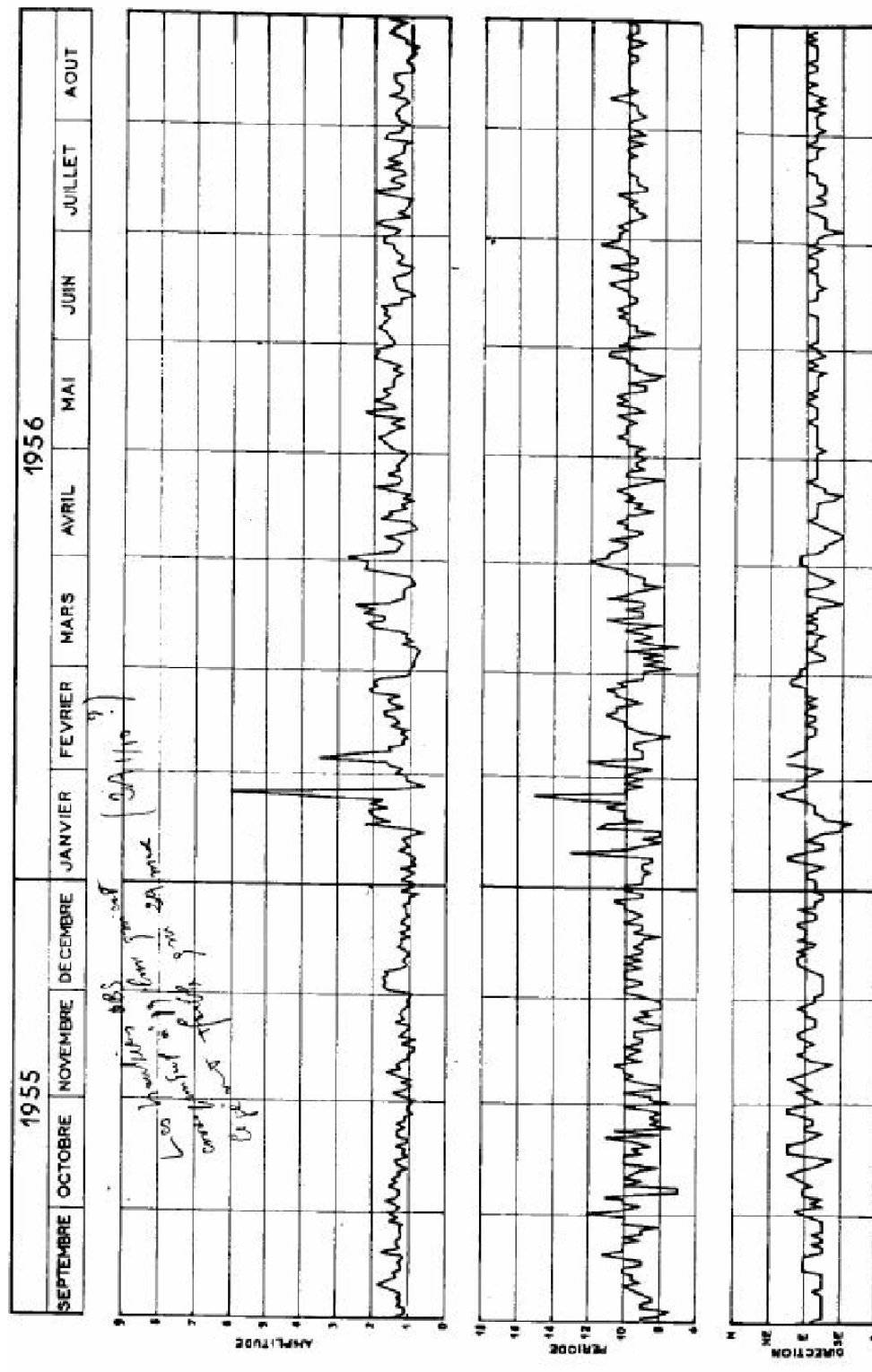


Figure 3.5: Graphic representation of directional wave measurements (BCEOM and DHI, 1955 & 1956).

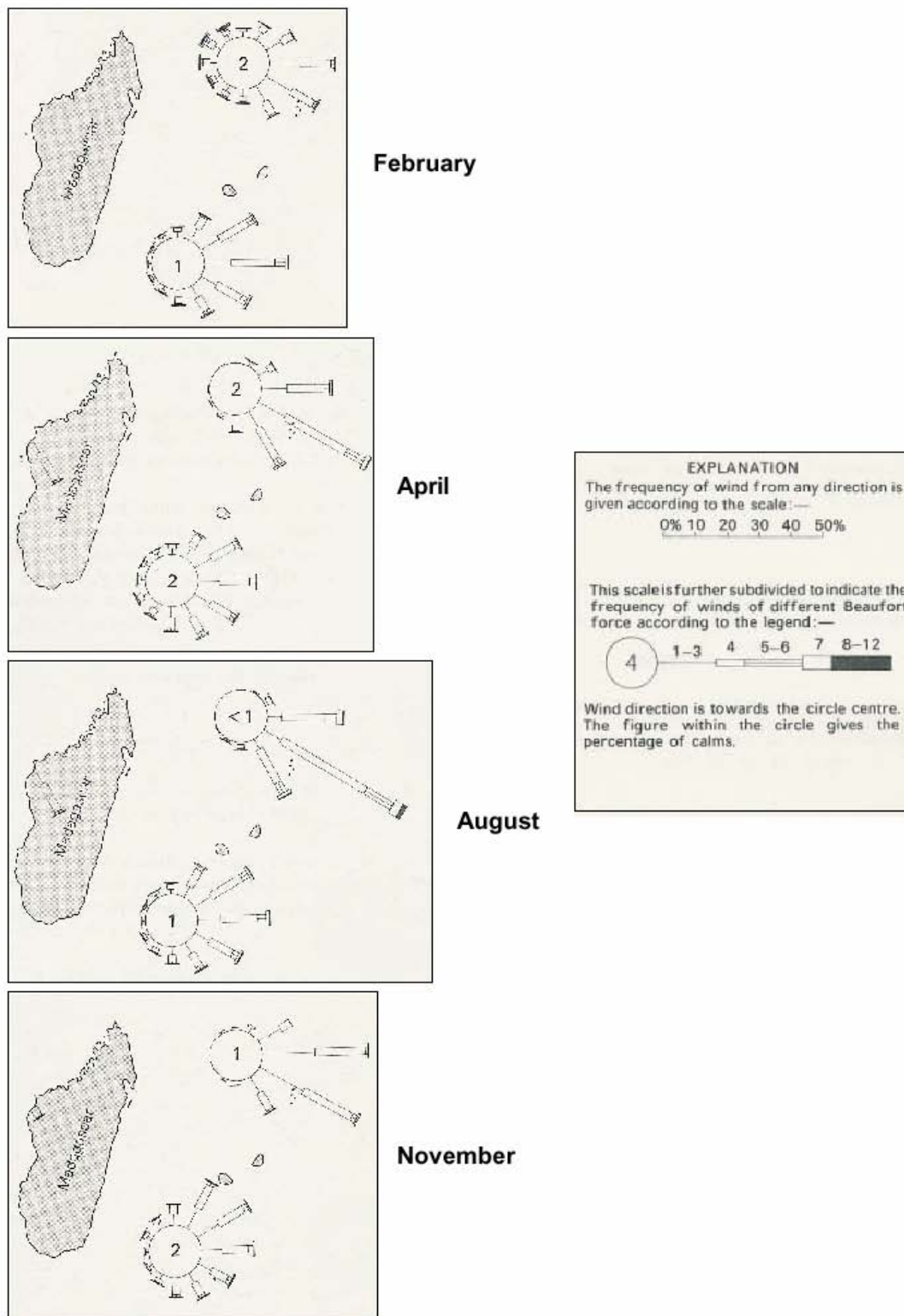
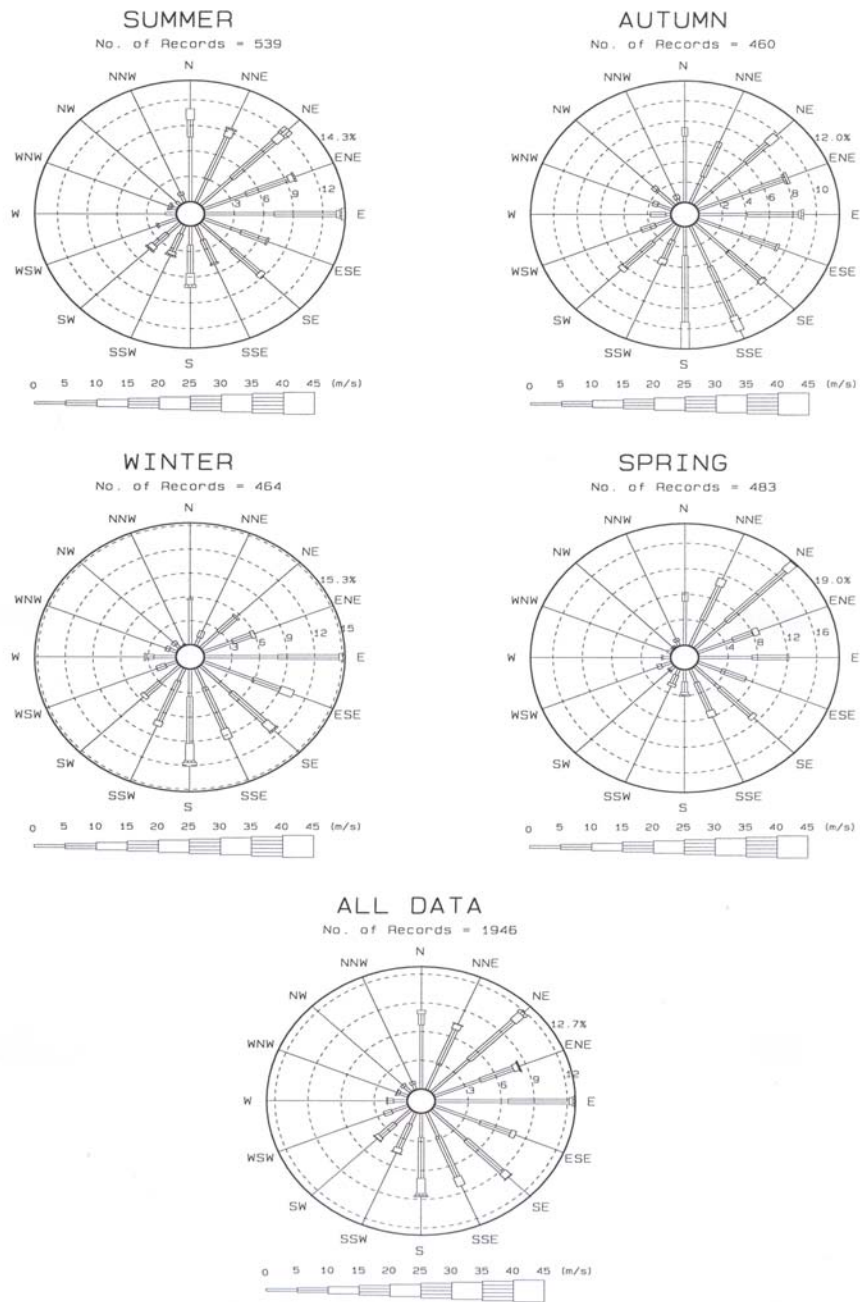


Figure 3.6: Wind roses for the East coast of Madagascar (South Indian Ocean Plot).

Seasonal wind roses from RN Hydrographic Office (1990) are shown in Figure 3.6 for locations to the north and south of Tamatave. These roses show that winds are predominantly from the east but that winds of up to approximately 20 m/s (Beaufort scale 8) can occur from a range of directions. More site specific wind data were obtained from the CSIR based on voluntary observing ships recordings (VOS). Seasonal and annual wind roses from the VOS data are shown in Figure 3.7. These roses show similar trends to those from RN Hydrographic Office (1990). The wind climate shows a strong seasonal influence. This was confirmed by the chief pilot of Tamatave port who described the general wind climate as being southerly from February to September (trade winds) with more northerly winds during the period from October to January. The southerly trade winds are usually from the south east in the morning becoming south west in the afternoon. Extreme winds occur in the form of cyclones that hit Madagascar on a regular basis (BCEOM and DHI, 1986). The maximum wind velocity that has been measured during a cyclone at Tamatave is 180 km/hour. A total of 64 cyclones passed within 500 km of Tamatave in the period 1961 to 1979, which gives an average of 3.5 per year. Of the cyclones occurring during this period 94% had a central pressure of 755 millibars or less. Figure 3.8 shows current roses for the Tamatave area from RN Hydrographic Office (1990). These currents apply to deeper water than that of the outfall and without measurements it is difficult to assess to what extent they will influence nearshore currents. It is expected that currents at the outfall will be predominantly driven by tides and wind. RN Hydrographic Office (1990) describes tidal currents as relatively weak along the Madagascar coast. This was confirmed in discussions with Tamatave pilots who indicated that tidal currents were generally not strong and that a maximum current velocity of 1 m/s can be expected during spring tides. These currents are aligned with the coast and flow in a northerly direction on a rising tide and southerly on a falling tide.

Current measurements were carried out with a mechanical current meter and drogue tracking on 3 June 2004 from 10:00 to 10:30. Problems with the boat and fairly rough seas forced the skipper to turn back to port before reaching the proposed outfall location. It was decided to measure the current at that point to obtain a first indication of what might be expected at the outfall. The wind direction was estimated as SSW with a speed of approximately 35 km/hour (9.7 m/s). A floating plant, with only the top section above water and the remainder (including roots) below water level, was used as drogue. The drogue track was fixed with a GPS and is shown in Figure 3.9. An average speed of 0.65 m/s was calculated for the drogue, which should give a good estimate of the surface water speed. A mechanical current meter was used to measure the current speed one meter below the water surface. An average value was determined over a four minute period as 0.69 m/s which corresponds well with the value determined using the drogue.

For calculating current speeds that are generated by wind, a value of between 1 to 3 percent of the wind speed is usually applicable. Using the upper value of this guideline would give a current speed of 0.2 m/s. It would therefore appear that it was not only the wind generating the current, since the current was approximately 0.42 m/s faster than what would be expected. The additional current was presumably due to the rising tide. Tidal predictions (WXTIDE) for 3 June 2004 are shown in Table 3.3.



(Approx. 1 observation per 3 days over 14 years)

Figure 3.7: VOS wind roses – seasonal as well as all data combined.

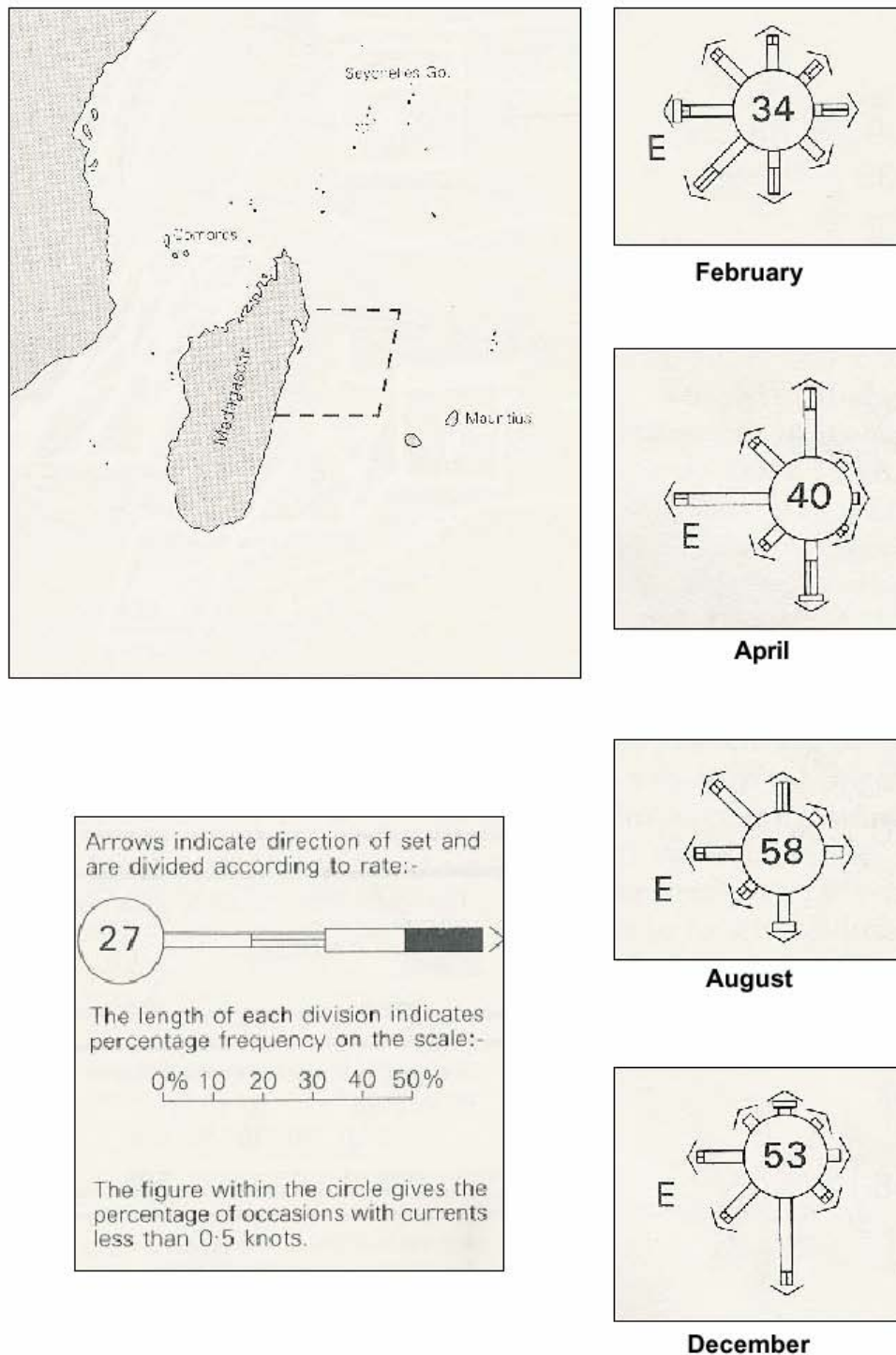


Figure 3.8: Predominant currents and current distribution off the East coast of Madagascar (South Indian Ocean Plot).

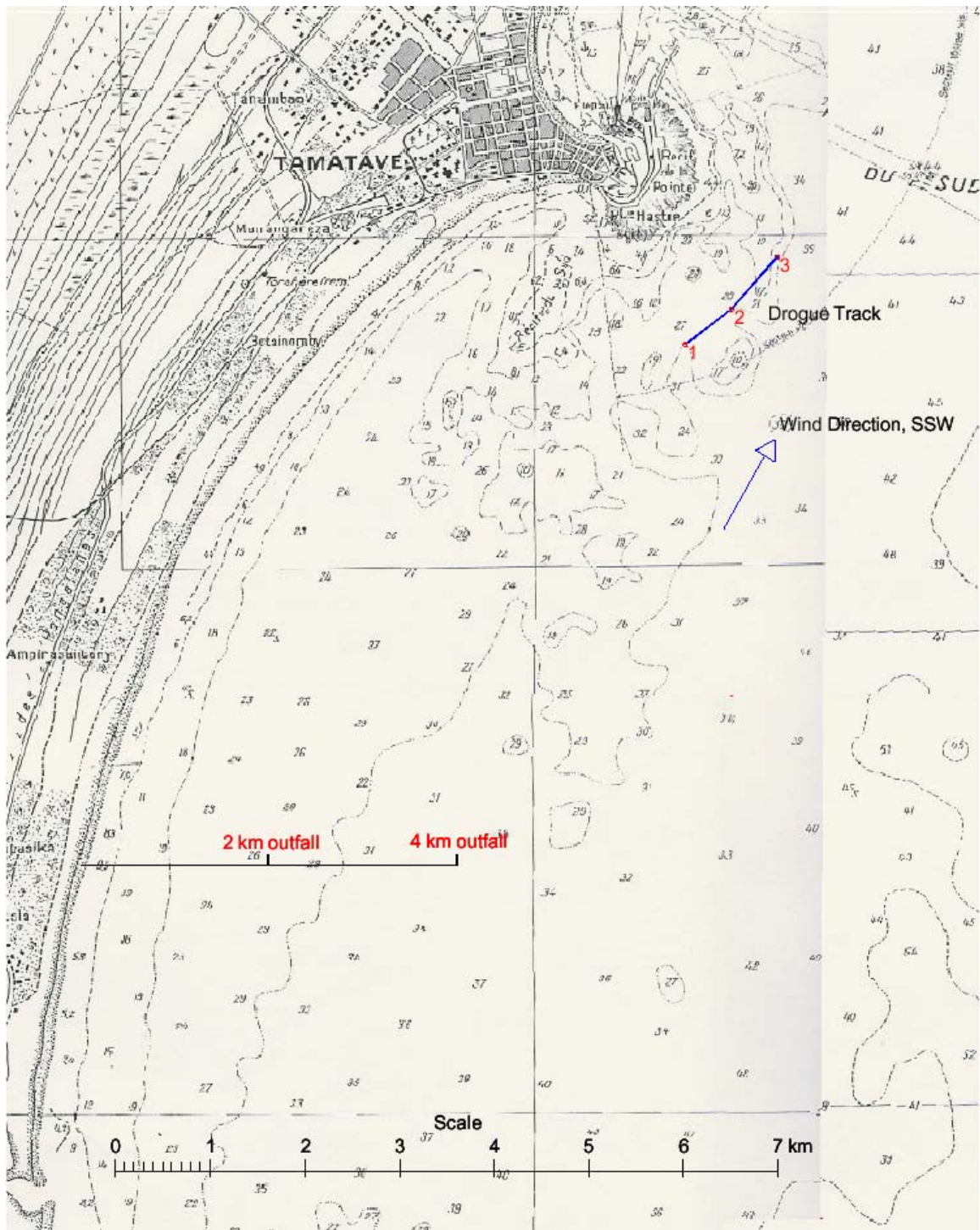


Figure 3.9: Illustration of drogue track measured during the site visit on June 3rd 2004.

The outfall lengths indicated are for reference only.

Table 3.3: Tidal predictions (WXTIDE) for 3 June 2004 at Tamatave.

Time	Tide (m CD)
01:00	0.90
07:17	0.25
13:41	1.04
20:07	0.35

This tidal range corresponds to the mean spring tidal range and a maximum northerly current of up to 1 m/s could be possible under these conditions (according to the harbour pilot).

Current measurements reported by BCEOM and DHI (1986) were measured from 1954 to 1956 at a number of locations on the inside of the harbour and at the head of the breakwater as indicated in Figure 3.3. In general currents were found to be weak at approximately 0.05 to 0.1 m/s, a fact confirmed in discussions with the harbour pilots.

The regional oceanography is of interest as Tamatave falls within a zone of current convergence (Dr William Rakotoarinivo, Oceanographer at SAGE, pers. comm.). When interviewed during our visit, Dr Rakotoarinivo reported that the southward flowing East Madagascar Current generates an offshore reverse current between it and Ile Sainte-Marie, and immediately to the south. Further to the south, the East Madagascar current generates inshore, northward-flowing reversal currents. Tamatave lies within the convergence of these two systems. In summer, the current regime results in low-grade upwelling south of Ile Sainte-Marie, further contributing to the turbidity in the area. On a larger scale, offshore oceanic currents are highly variable, but are generally north to south (Anon. 2002).

No previous studies regarding sediment movement were available. Dredging records from the port indicate that sand moves in a southward direction that requires periodic maintenance dredging on the shoreward side of Mole A. According to Port authorities, no dredging has apparently been carried out at the head of the breakwater.

The combination of high summer rainfall, terrestrial sediments, cyclones and strong winter winds cause nearly year-round turbidity in the region. Annual rainfall in the Toamasina district ranged from 1 961 to 2 928 mm per annum between 1993 and 2000 (Anon. 2002). The area is thus not conducive to coral reef development, and the damage caused by cyclones and rough seas adds to this stress. These local conditions are highlighted at an early stage in the report, as they have a profound effect on coral development. In Dr. Rakotoarivino's opinion, the reefs in the Tamatave region have been in decline for many years. A publication highlighting environmental indicators in the Province of Toamasina indicates major littoral reef complexes, none of which are near the Tamatave region. The closest reef of consequence is indicated at Ile Sainte Marie over 60 nm to the north (Anon. 2002). There are no marine protected areas in the Province.

Coral reefs in the immediate region are found at:

- Ile aux Prunes, approximately seven nautical miles north of Tamatave.
- Le Grand Recif, immediately to the north of the harbour.
- Recif de la Pointe, at the point of the harbour mouth and seaward of southern breakwater.
- Recif du Sud, immediately to the south of the harbour.
- Nosy Faho, approximately eight nautical miles to the south of Tamatave.

3.2 THE CORAL REEF HABITAT

Corals are coelenterates, making them relatives of anemones and jellyfish. Most are colonial and they possess the tentacles and stinging cells that typify this group. The best known corals are those which build reefs and these are referred to as hermatypic stony corals. Although they are animals, hermatypic corals possess symbiotic algae within their tissues, forming a plant-animal association in which nutrients and the products of photosynthesis are mutually shared. They were often considered to be plants by early workers because of this attribute as well as their growth form. They are also partially mineral since they deposit heavy aragonite skeletons as a by-product of their metabolic activities. Accumulations of these supporting structures form true coral reefs.

Some stony corals do not possess symbiotic algae and are thus ahermatypic and are not considered reef builders. They produce skeletons but these are generally less massive than those deposited by hermatypic corals.

There is yet another large group of corals which usually have symbiotic algae but do not deposit solid skeletons. They are the soft corals, so called because they are leathery to the touch and only produce calcareous needle-like structures for skeletal support. These structures are termed sclerites and generate sand rather than reefs upon death of the coral colony.

Corals require stringent conditions for their survival. They only grow in seawater that is warm, of normal salinity, clean and not stagnant. Water clarity is needed for light penetration, as most corals are dependent on the photosynthetic activity of their symbiotic algae for survival. Turbidity caused by suspended sediment or a proliferation of algae in the water after nutrient enrichment thus precludes their growth. Disturbances in their environment can trigger an overnight loss of their symbiotic algae, resulting in coral bleaching and death. This may be caused by a number of factors, most notable of which are increases in sea temperature beyond their normal tolerance. In addition, corals are susceptible to pollutants, especially the metals used in anti-fouling paints (e.g. copper and tin) and diesel and bunker fuel. Most corals are not emergent and are generally not directly affected by oil pollution, but volatile components penetrate the water column and affect their metabolism and reproduction.

Coral reefs are considered an invaluable natural asset. They are extremely productive ecosystems with a biodiversity value comparable to or greater than that of the Amazon Forest. They are important nursery and feeding grounds for edible fish, a source of natural products in the search for new pharmaceuticals and are prized by the ecotourism industry for diving ventures. Human activities such as dredging, dynamite fishing, coral mining and coastal development as well as the indirect consequences of human perturbation (global warming and crown-of-thorns starfish outbreaks) are endangering their existence. Recent estimates have indicated that they are currently diminishing by as much as 5% p.a. and international concern for their conservation is increasing. Catastrophic bleaching with far greater mortality followed an increase in sea temperature during the 1998 El Nino Southern Oscillation (ENSO).

As a direct consequence of the facts mentioned above, coral reefs are listed as an environmental priority by international organizations such as the World Bank, UNEP, IUCN and WWF, and are given special protection under international law (CITES, the Convention for the International Trade in Endangered Species).

3.2.1 REEF SURVEY

General

The regional oceanography is of interest as Tamatave falls within a zone of current convergence (Rakotoarinivo*, pers. comm.). When interviewed during the first visit, Rakotoarinivo reported that the southward flowing East Madagascar Current generates an offshore reverse current in the region just south of Ile Sainte-Marie between it and the mainland. Further to the south, the East Madagascar current generates inshore, northward-flowing reversal currents. Tamatave lies within the convergence of these two systems. In summer, the current regime results in low grade upwelling south of Ile Sainte-Marie, causing turbidity in the area. The wet, cyclonic season (November-March) results in considerable erosive run-off from the steep east coast, adding further to the natural background turbidity. However, this has been exacerbated by agriculture within the river catchments and, in recent years, by open-cast graphite mining in the coastal mountains. These factors, together with prevailing southerly winds in the winter months, cause nearly year-round turbidity in the region. The area is thus not conducive to coral reef development and the damage caused by cyclones and associated stormy seas add to this stress. These local conditions are highlighted at an early stage in the report as they have a profound effect on coral development. In Rakotoarinivo's opinion, the reefs in the Tamatave region have been in decline for many years.

The reefs around Tamatave were, by-and-large, fairly homogenous. They were relatively flat in profile, probably due to rigorous conditions generated by frequent cyclonic seas, and they formed shallow fringing reefs, with the exception of Recif du Sud, which shelved off at a depth of 5 m. Most reef profiles were only broken by shallow gulleys, forming spur and groove formations. In a few instances, the reefs rose on the seaward side in a steep wall before flattening out. Reefs observed were poor in terms of their

* William Rakotoarinivo (Doctorate in Oceanography), SAGE

biodiversity. A list of organisms observed on the reefs is presented in Table 3.7, however, the numerous species listings may be misleading; as many observations arose from single sightings.

Methods

Coral reefs are found in the region primarily at (Fig. 3.10):

- Ile aux Prunes, approximately 10 nautical miles north of Tamatave;
- Banc des Six Metres, immediately to the south of Ile aux Prunes;
- Le Grand Recif, immediately to the north of the harbour;
- Recif de la Pointe, at the point of the harbour mouth;
- Recif du Sud, immediately to the south of the harbour;
- Nosy Faho, approximately 17 nautical miles to the south of Tamatave;
- Nosy Dombala, 10 nautical miles to the south of the proposed marine outfall;
- Nosy Fonga, immediately to the south of Nosy Dombala; and
- Banc Malagasy, a submerged bank between Nosy Faho and Nosy Dombala.

Sampling sites and protocol

A visit was made to Madagascar from 1-10 June 2004, during which five days were spent undertaking a qualitative assessment of the reefs around Tamatave. Where possible, SCUBA and snorkel diving was undertaken on representative areas of the reefs. Poor diving conditions were experienced throughout the trip and precluded a visit to Recif de la Pointe. Operations were also logistically limited by unfavourable sea conditions and the distance to the reefs. Apart from the coral reefs, a dive was made on a rocky feature charted at some depth (18-23 m) just south of Recif du Sud.

A coral species list was compiled as far as possible (Table 3.7), notes were made on the reef type and morphology, preliminary transects of the reefs were recorded using a digital camera and photographs were taken of typical coral communities where conditions permitted. Corals can generally only be identified from the microscopic examination of carefully prepared and preserved specimens. Such a collection was not possible within the time constraints of these surveys and the identifications provided in the species list are thus presumptive.

Follow-up surveys were undertaken during 31 July - 14 August 2005. While the logistical support was greatly improved, operations were again limited by inclement weather and unfavourable sea conditions. Nevertheless, on this occasion, sufficient digital images of quadrats were recorded at sites on all but one of the aforementioned reefs to enable quantitative analysis of the data for information on coral community structure. The images were recorded with a digital camera equipped with a spacer bar so that the quadrat size was standardized (0.3 m²). The recordings were made along transects in a randomized fashion, this being accomplished both by the surge interval of the swell and the recording interval of the camera.

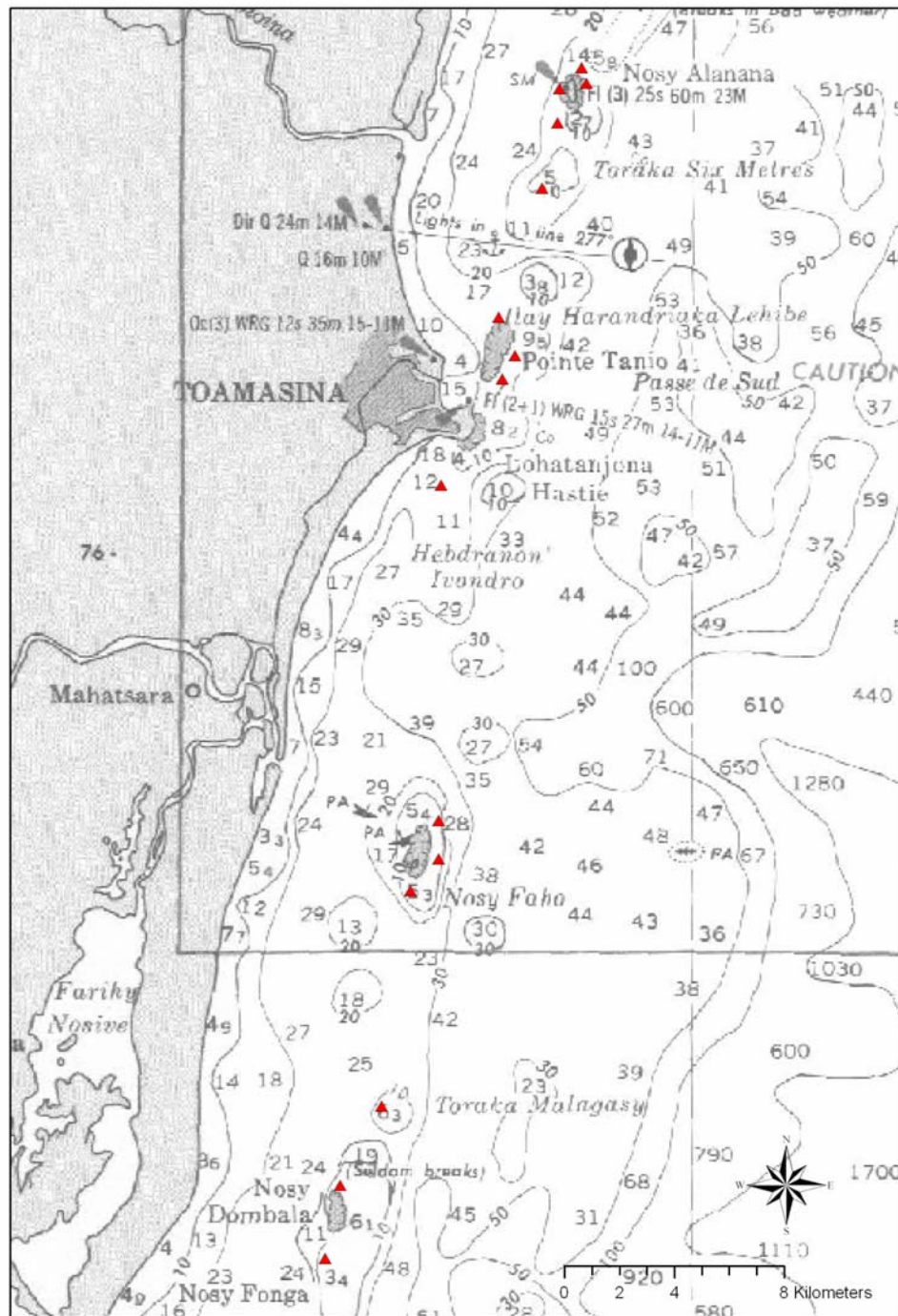


Figure 3.10: Map of the study area showing the sites off Tamatave at which digital images of quadrats were recorded along reef transects. Map by courtesy of the Marine Geoscience Unit.

Data Analysis

The quadrat images were analyzed using a point intercept technique to establish the community structure of the benthos. This was done using a rapid video survey technique developed at ORI in which the images were screened and the biota or substratum were recorded under ten randomly-placed points on the computer screen. While a record of the biota was kept to genus level, and often species level, the percentage cover of the biota in each transect was calculated according to both genus and morphological category. The life forms devised by English *et al.* (1994) were used for the latter purpose, with additional categories to cater for the greater abundance and diversity of soft corals and sponges on reefs in the south-western Indian Ocean (SWIO) (Table 3.4).

The transect data on community structure were subjected to similarity analysis using multivariate classification and ordination techniques to detect distinct communities on the reefs. Multi-dimensional scaling (MDS) yielded the most meaningful result in characterizing the coral communities. This was undertaken on the standardized multivariate data set in terms of normalized Euclidean distances. Using this technique, the separation between transect sites in a 2-dimensional MDS plot reflects their relative similarity/dissimilarity within the suite of selected variables. The overall performance of the analysis in terms of 'goodness-of-fit' is expressed as a stress coefficient (Kruskal stress coefficient). This is calculated as scatter in the data around the non-parametric regression line in an MDS plot of dissimilarities in the Euclidean matrix. The statistically derived groupings were compared with the communities observed in the field and used to describe the reef types.

Results

Photographic quadrats were obtained during 15 of the 20 dives that were executed in 2005 (Fig. 3.10), yielding representative information on all of the reef types. The images varied in quality as they were obtained in visibilities ranging from 0.5-7 m. The balance of the dives proved unproductive because either the bottom visibility was zero or the dives fell on sand, despite being located in areas charted as reef. The poor water visibility was attributable to rough sea conditions throughout the survey period, due to strong, predominantly southerly winds. As a result, the swell height ranged between 1.5 - 3 m with a commensurate bottom surge.

The reefs that were surveyed proved to be fairly homogenous (Table 3.5). They are relatively flat in profile, probably due to rigorous conditions generated by frequent cyclonic seas, and they form shallow fringing reefs except for Recif du Sud which shelves off at a depth of 5 m.

The sites at which reef assessments were made in 2005 are listed in Table 3.6. In all, 860 quadrat images were recorded, ranging from 42 to 105 images per usable transect. This constituted a reef area of 262 m². Habitat photographs were recorded in a few localities where water clarity permitted.

The reefs were poor in terms of their biodiversity. A list of organisms observed on the reefs is presented in Table 3.7 but the length of this may be misleading; many observations arose from single sightings. Bleaching was encountered on most of the reefs (Table 3.5).

Results of analyses and individual site descriptions

A summary of the results of the coral community studies is presented in Tables 3.7 and 3.8. With few exceptions, the reefs were characterized by relatively low to moderate coral cover with considerable dead coral and exposed substratum. The results will be discussed later in terms of their significance but will first be placed in context with site descriptions.

Table 3.4: Categories of organism or reef cover recorded during point intercept data extracted from the digital images of quadrats recorded along reef transects at the study sites off Tamatave. These were categorised according to the system devised by English *et al.* (1994).

Category	Life Form	Code
Hard coral: Acropora	Acropora, branching	ACB
	Acropora, encrusting	ACE
	Acropora, submassive	ACS
	Acropora, digitate	ACD
	Acropora, tabular	ACT
Hard coral: Non-Acropora	Encrusting plates	CE
	Foliose	CF
	Massive	CM
	Submassive	CS
	Mushroom	CMR
	Millepora	CME
Soft coral	Arborescent (e.g. <i>Sinularia heterospiculata</i> , <i>Dendronephthya</i>)	SCA
	Digitate (e.g. <i>Alcyonium</i> , some <i>Cladiella</i> sp.)	SCD
	Floral (e.g. <i>Anthelia</i> , <i>Heteroxenia</i> and <i>Xenia</i>)	SCF
	Encrusting (e.g. <i>Lobophytum</i>)	SCE
	Massive (e.g. <i>Sarcophyton</i>)	SCM
Black coral and gorgonians	Black coral	BC
	Gorgonian	GO
Sponges	Encrusting	SPE
	Laminar	SPL
	Vasiform	SPV
	Massive	SPM
Other	Algal assemblage	AA
	Coralline algae	CA
	Halimeda	HA
	Macro-algae	MA
	Turf algae	TA
	Dead coral	DC
	Dead coral and algae	DCA
	Sand	S
	Rubble	R
	Rubble and algae	RA
	Rock	RCK

Table 3.5: Details on the reefs dived at the study sites off Tamatave.

Reef	Ile aux Prunes				Banc des Six Metres
Site	NW point	W	S	E	
Reef type	Fringing reef	Patch reefs	Fringing reef		Shallow reef bank
	Flat spur and groove reef	Small, isolated "bommies"	Deep spur and groove ridges of good profile (20 m wide and 6 m high)	Very flat reef with shallow gullies	Reef rising from a broken wall into flat spur and groove formations
Depth (m)	10 to 16	10	15 to 22	10 to 12	10 to 14
Visibility (m)	2 to 3	1 to 2	4 to 5	2 to 3	1 to 4
Bleaching	Yes	Yes	Yes	Yes	Yes

Reef	Le Grande Recif				Recif du Sud
Site	NW point	SE	E side		
Reef type	Fringing atoll				Fringing reef
	Broken reef	Reef rising from a broken wall into boulders and deep spur and groove formations	Reef rising from a broken wall into boulders and deep spur and groove formations		Steep outer reef rising to flat reef with shallow gullies
Depth (m)	6 to 16	8 to 16	9 to 13		6 to 17
Visibility (m)	2 to 4	<1	1 to 2		0.5
Bleaching	No	Yes	Yes		Yes

Reef	Nosy Faho			Banc Malagasy	Nosy Dombala	Nosy Fonga
Site	NE point	S	E		N point	N passage
Reef type	Fringing atoll			Reef bank	Fringing atoll	Patch reef
	Flat reef with shallow gullies	Reef ridge rising in a steep wall	Reef rising slowly in broad, flattened ridges with fairly deep gullies	Very flat and broad spur and groove formations	Moderately pronounced spur and groove formations	Broken reef and bommies
Depth (m)	9 to 15	9 to 22	10 to 16	13 to 18	10 to 13	8 to 13.5
Visibility (m)	4 to 7	4 to 5	5 to 7	4 to 6	5 to 6	5 to 7
Bleaching	No	No	No	No	No	Yes

Table 3.6: Co-ordinates of the study sites off Tamatave at which digital images of quadrats were recorded along reef transects (N = number of quadrats).

LOCATION	LATITUDE	LONGITUDE	N
Ile aux Prunes NW	18° 02.521'S	49° 27.841'E	47
Ile aux Prunes W	18° 02.934'S	49° 27.410'E	42
Ile aux Prunes S	18° 03.598'S	49° 27.372'E	63
Ile aux Prunes E	18° 02.818'S	49° 27.943'E	67
Banc des Six Metres	18° 04.897'S	49° 27.072'E	49
Le Grand Recif NW	18° 07.437'S	49° 26.219'E	57
Le Grand Recif SE	18° 08.643'S	49° 26.282'E	43
Le Grand Recif E	18° 08.187'S	49° 26.534'E	42
Recif de la Pointe	18° 09.394'S	49° 26.250'E	2
Recif du Sud	18° 10.742'S	49° 25.082'E	45
Nosy Faho NE	18° 17.350'S	49° 25.031'E	68
Nosy Faho S	18° 18.729'S	49° 24.474'E	57
Nosy Faho E	18° 18.103'S	49° 25.001'E	53
Banc Malagasy	18° 22.962'S	49° 23.913'E	64
Nosy Dombala N	18° 24.532'S	49° 23.091'E	56
Nosy Fonga Passage	18° 25.966'S	49° 22.798'E	105

Ile aux Prunes

Ile aux Prunes is a small yet well-vegetated island with a lighthouse. There was evidence of fishing activity on the island and it has a recent shipwreck on the southern side. Sea conditions limited survey operations in the NW, along the inner edge and SW region of the island but a comprehensive dive was possible on its eastern seaward side (Photo Plates 3.3 and 3.4).

The reefs in the NW consisted of flat spurs interspersed by shallow gullies with a moderate coral cover. The gullies were filled with accumulated coral rubble. Shallow areas that were snorkeled were nearly bare, probably due to ENSO-related coral bleaching. Those on the western, sheltered side consisted of broken, patch reefs or “bommies” subjected to high turbidity and considerable sedimentation; their coral cover was poor. Some of the reef surface that had been exposed for some time had become heavily colonized by the giant clownfish anemone, *Heteractis magnifica*. A reef of substantial profile, consisting of deep spur and groove ridges 6m high and 20 m wide, was found on the southern side. This was dominated by a high cover of *Pachyseris speciosa*, a species again attesting to high turbidity in the area as it is adapted to low light intensities and often found at greater depths. A species associated with reef margins was similarly found here (*Seriatopora caliendrum*); it is also susceptible to bleaching. An extensive and remarkably flat reef was found on the seaward side of the island; this had a moderate coral cover.

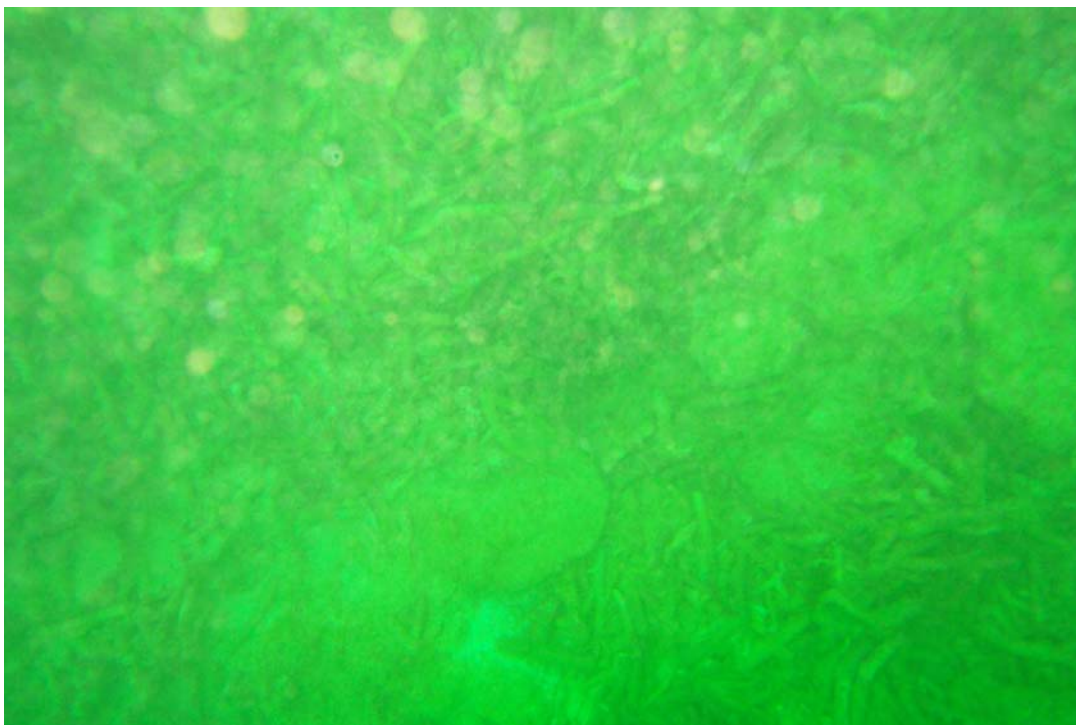


Photo Plate 3.3: Accumulated coral rubble in a turbid reef gulley off Ile aux Prunes.



Photo Plate 3.4: A resilient community of corals of the genus *Acropora* in turbid water off Ile aux Prunes.

Banc des Six Metres

This is a shallow, submerged bank that was hazardous to work on due to shoaling water in heavy seas. The coral reef in its centre rises in a broken wall with flat spur and groove formations. It had reasonable living coral cover but much of the reef was dead.

Table 3.7: Presumptive identification of the major biota observed on the reefs in the region of Tamatave. These are listed in alphabetic rather than phylogenetic order.

	Ile aux Prunes	Banc des Six Metres	Le Grand Recif	Recif du Sud	Nosy Faho	Banc Malagasy	Nosy Dombala	Nosy Fonga
ALCYONACEA								
(Soft corals)								
<i>Anthelia glauca</i>				+				
<i>Cladiella australis</i>	+	+		+	+			+
<i>Cladiella laciniosa</i>	+	+						
<i>Cladiella</i> sp.			+		+	+	+	+
<i>Cespitularia</i> sp.	+	+	+	+	+	+	+	+
<i>Lobophytum crassum</i>	+		+		+			+
<i>Lobophytum depressum</i>	+	+	+	+	+	+	+	+
<i>Lobophytum patulum</i>	+							
<i>Lobophytum venustum</i>				+				
<i>Rhytisma fulvum fulvum</i>	+				+	+	+	+
<i>Rumphella</i> sp.	+				+		+	
<i>Sarcophyton</i> sp.	+	+			+			+
<i>Sinularia abrupta</i>	+	+	+	+	+	+	+	
<i>Sinularia brassica</i>	+	+	+	+	+		+	
<i>Sinularia firma</i>			+	+	+			
<i>Sinularia gravis</i>	+	+	+	+	+	+		
<i>Sinularia heterospiculata</i>					+			+
<i>Sinularia polydactyla</i>			+					
<i>Sinularia variabilis</i>	+		+	+	+			
<i>Sinularia</i> sp.	+							
SCLERACTINIA								
(Stony corals)								
<i>Acanthastrea echinata</i>			+		+		+	+
<i>Acropora appressa</i>			+		+			
<i>Acropora austera</i>	+			+	+			
<i>Acropora clathrata</i>	+	+	+	+	+			
<i>Acropora cytherea</i>	+				+			
<i>Acropora danae</i>	+		+	+				
<i>Acropora digitifera</i>	+		+		+			
<i>Acropora horrida</i>					+			
<i>Acropora humilis</i>	+							

	Ile aux Prunes	Banc des Six Metres	Le Grand Recif	Recif du Sud	Nosy Faho	Banc Malagasy	Nosy Dombala	Nosy Fonga
Acropora hyacinthus	+		+	+	+			
Acropora palifera			+		+			
Acropora millepora					+			
Acropora robusta	+	+	+	+	+			
Acropora sp.	+		+			+	+	+
Alveopora allingi	+				+			+
Astreopora myriophthalma	+	+	+	+	+	+	+	+
Anomastrea irregularis	+		+					
Blastomussa merletti				+	+			
Coscinarea monile	+			+	+			+
Cyphastrea microphthalma				+	+			
Diploastrea heliopora	+							
Echinophyllia aspera	+			+				+
Echinopora gemmacea	+	+	+	+	+	+	+	+
Favia favius	+		+	+	+			
Favia pallida					+			
Favia rotundata			+	+	+			
Favia speciosa					+			
Favia stelligera					+			
Favia spp.	+	+	+	+	+	+	+	+
Favites abdita			+		+			
Favites complanata	+		+	+	+			
Favites flexuosa	+	+	+	+	+		+	+
Favites pentagona	+		+		+			
Favites peresi	+		+		+	+	+	+
Favites spp.	+		+	+	+	+		
Fungia spp.	+		+		+			+
Galaxea astreata	+	+	+		+	+	+	+
Galaxea fascicularis	+		+	+	+	+	+	+
Gardinoseris planulata			+					
Goniastrea pectinata	+							
Goniopora djiboutiensis	+						+	+
Gyrosmlia interrupta			+					+
Halomitra pileus	+							
Hydnophora exesa	+	+	+	+	+			+
Leptastrea inaequalis			+					+
Leptoseris explanata	+		+	+	+			
Lobophyllia corymbosa	+	+	+	+	+	+		+
Lobophyllia hemprichii	+							
Montastrea sp.								+
Montipora aequituberculata			+		+			
Montipora monasteriata	+		+		+	+		
Montipora tuberculosa	+		+	+				
Montipora spp.	+		+	+	+		+	+

	Ile aux Prunes	Banc des Six Metres	Le Grand Recif	Recif du Sud	Nosy Faho	Banc Malagasy	Nosy Dombala	Nosy Fonga
Mycedium elephantosus	+		+	+	+	+		
Oulophyllia crispa	+		+	+			+	+
Oxypora lacera	+			+				+
Pachyseris speciosa	+		+	+				
Pavona clavus			+	+			+	
Platygyra daedalea	+	+	+	+	+		+	
Platygyra sinensis	+		+	+	+		+	+
Pocillopora damicornis		+		+	+	+		
Pocillopora eydouxi	+		+	+	+			
Pocillopora verrucosa	+		+	+	+	+	+	
Porites cylindrica/nigrescens	+		+		+		+	
Porites lutea	+				+			
Porites rus	+	+	+		+			+
Porites solida			+		+			+
Porites sp.	+		+		+	+	+	+
Psammocora haimeana	+			+	+	+	+	+
Seriatopora caliendrum	+							
Stylophora pistillata			+	+				
Stylophora pistillata mordax	+			+	+			
Symphyllia valenciennesii					+			+
Turbinaria mesenterina	+	+	+	+	+	+	+	+
MILLEPORINA								
(Fire coral)								
Millepora platyphylla					+			
Millepora tenella	+		+		+			
HYDROZOA								
Aglaeophenia cupressina							+	
ANTHOZOA								
(Anemones)								
Heteractis magnifica	+				+			
CORALLIOMORPHARIA	+							
ZOANTHARIA								
(Zoanthids)								
Palythoa cf natalensis	+		+		+			
PORIFERA								
(Sponges)								
Anthosigmella orientalis	+							+
Dysidea sp.	+							
Oceanapia aff. ramsayi					+			
Petrosia sp.				+				
Reniochalina stalagmites								
Suberites kelleri				+	+			+
Xestospongia sp.	+		+		+			
ECHINODERMATA								

	Ile aux Prunes	Banc des Six Metres	Le Grand Recif	Recif du Sud	Nosy Faho	Banc Malagasy	Nosy Dombala	Nosy Fonga
(Sea urchins, starfish and sea cucumbers)								
Culcita sp.					+			
Diadema sp.	+		+	+	+			
Holothuria sp.	+							
MOLLUSCA								
Tridacna sp.	+		+	+	+	+		
ASCIDIACEA								
(Sea squirts)								
Didemnum molle								+
Pseudodistoma africanum						+		
ALGAE								
Caulerpa sp.					+			
Halimeda sp.	+		+		+	+		+
Coralline algae			+	+	+			
Unidentified algae								

Le Grand Recif

This is the biggest reef in the region, almost a fringing atoll, yet is devoid of conspicuous vegetation having an exposed sand spit used by fishermen). Under varying conditions, dives on the NW point of the atoll as well as the SE point and E side of the atoll were possible. The dive at the NW point was slightly further west of the 2004 site, which was unapproachable due to heavy seas during the survey despite the better craft. The reef at the NW site visited in 2005 was more broken but otherwise similar to the 2004 site and had an impoverished coral community. The other dive sites on Le Grand Recif rose steeply into broken spur and groove formations and boulders of good profile and moderate coral cover. The latter was lowest at the SE site and areas not populated by corals were heavily overgrown by encrusting coralline algae, a condition denoting persistent coral decolonization. An attempt to dive on the southernmost point of Le Grand Recif was not fruitful due to extremely high turbidity (<0.5 m). However, the reef profile appeared to be similar to that at the SE site, but the coral community appeared to be bleached and impoverished.

Dives undertaken in search of reefs revealed a sand bank on the north of Le Grand Recif and deeper channels (≥ 20 m) onto sandy substrata on the western side. These channels were characterized by high turbidity (visibility ≤ 0.5 m) and accumulated deposits of very fine sediment that was easily re-suspended.

Table 3.8: Benthic categories and taxa that attained more than 5% cover on any one reef at the study sites off Tamatave.

Site		Ile aux Prunes NW	Ile aux Prunes W	Ile aux Prunes S	Ile aux Prunes E	Banc des Six Metres	Le Grand Recif N	Le Grand Recif SE	Le Grand Recif E	Recif du Sud	Nosy Faho N	Nosy Faho S	Nosy Faho E	Banc Malagasy	Nosy Dombala	Nosy Fonga
Scleractinia (Hard coral)		28	26	55	23	34	13	23	30	11	43	18	54	13	26	34
Alcyonacea (Soft coral)		8	9	1	8	8	4	9	6	22	3	11	2	4	2	7
Algae		2	3	8	7	11	3	33	8	22	4	8	4	5	5	2
Porifera (Sponges)		1	0	1	1	0	3	0	<1	1	1	4	<1	3	1	2
Actinidea (Anemones)		0	5	0	0	0	0	0	0	0	0	0	0	0	0	1
Substratum		60	54	33	59	39	78	27	49	44	47	58	38	73	63	55
Scleractinia	Acropora	7	5	3	5	9	1	3	7	5	21	5	32	<1	5	3
	Montipora	3	1	2	5	3	2	5	5	<1	3	2	2	1	3	2
	Galaxea	<1	7	2	0	2	0	2	5	1	1	1	<1	<1	<1	2
	Pachyseris	0	0	36	0	0	0	1	1	0	0	0	0	0	<1	0
	Porites	4	5	0	3	4	5	3	2	<1	6	4	10	3	5	17
	Turbinaria	<1	0	0	<1	4	1	<1	1	0	2	<1	1	2	4	1
Alcyonacea	Cespitularia	3	1	<1	1	<1	1	0	0	0	1	5	1	1	<1	4
	Sinularia	5	6	<1	4	7	3	8	6	22	2	5	1	2	1	2
Coraline encrusting algae		2	2	8	5	10	2	32	5	17	2	2	4	4	1	<1

Damage from fishing activities (net and anchor damage) was found on Le Grand Recif during shallow-water work accomplished during the 2004 survey (Schleyer, 2004). This had resulted in reef degradation and bio-erosion where it was found Photo Plate 3.5).

The inner reef break (18° 07.943'S; 49° 25.912'E) and reef in this gap consisted of large *Porites* domes in the past, but only one good specimen 4 m in diameter was still intact (Photo Plates 3.7 & 3.8). The others had been damaged by fishing activities, and the ingress of bio-eroders had variously reduced them to gnarled features (Photo Plates 3.18 and 3.1) either comprising a few species of corals, or a combination of fire coral (*Millepora*) and coralline algae. The biodiversity was commensurately low (Table 3.7).



Photo Plate 3.5: A gill net tangled in a mixed coral community on Le Grand Recif.



Photo Plate 3.6: Encrusting coralline algae surrounding a sparse mixed coral community on Le Grand Recif. The large central specimen is a soft coral, *Sinularia gravis*.



Photo Plate 3.7: The large intact *Porites* dome found on Le Grand Recif.



Photo Plate 3.8: A *Porites* dome on Le Grand Recif infested by bio-eroders (RHS) and invaded by the fire coral, *Millepora platyphylla* (LHS).



Photo Plate 3.9: A dead *Porites* dome on Le Grand Recif colonised by coralline algae and a sparse mixed coral community.

Recif de la Pointe

Attempt dives were made on Recif de la Pointe, which is submerged and abuts the harbour wall south of the harbour mouth. This was undertaken in extremely poor visibility (<0.5 m) and only yielded similar observations to those recorded at the southern end of Le Grand Recif (immediately to the north of the harbour). Reefs in the proximity of the harbour mouth, thus appear to share the consequences of extreme turbidity.

Recif du Sud

A dive was again undertaken on the east side of this reef under difficult conditions of poor visibility, strong currents and a powerful surge. The reef rises slowly from the seaward side and shelves off in a wave-cut platform. The hard coral cover on it was poor but it had a moderately high cover of the soft coral genus, *Sinularia*, on the shallow, reef flat; this is typical of such wave-cut platforms. This habitat was not found elsewhere during the survey and Recif du Sud thus had the highest biodiversity with some species not encountered on the other reefs investigated (Table 3.7). Coralline algae were abundant on areas depopulated of coral (Photo 3.10 and 3.11).

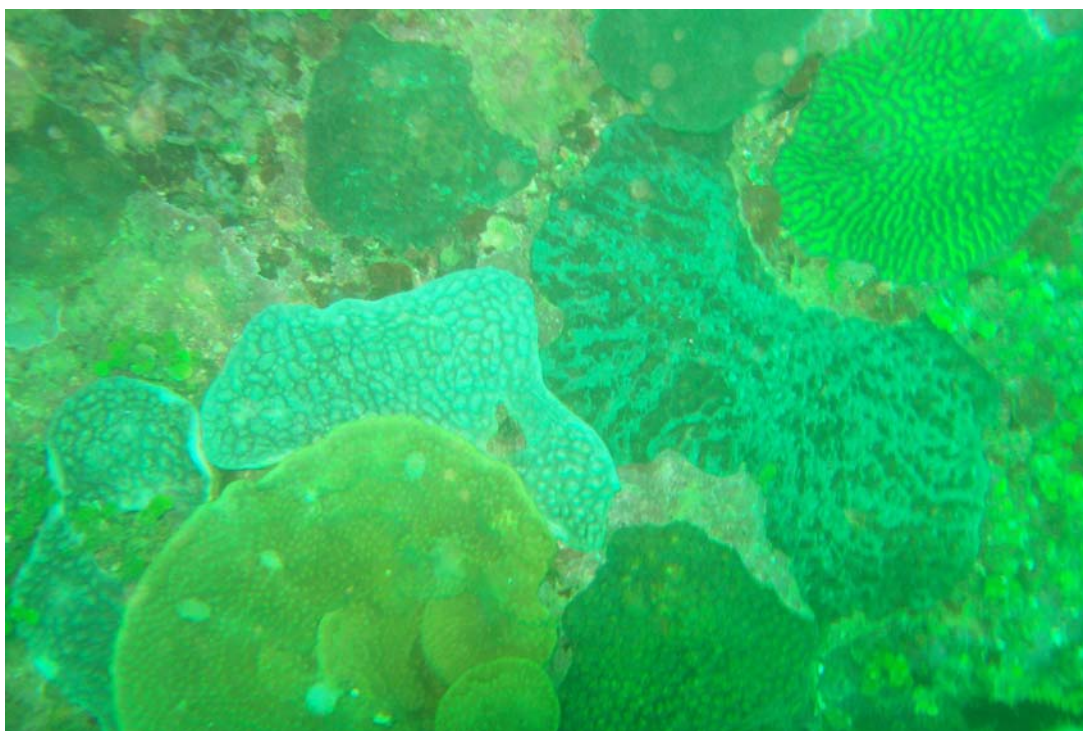


Photo Plate3.10: A mixed coral community interspersed by coralline algae on Recif du Sud.



Photo Plate 3.11: A large encrustation of the soft coral, *Sinularia abrupta* on Recif du Sud.

Nosy Faho

The best coral reefs were encountered around the northern and eastern sides of Nosy Faho, which has a conspicuous shipwreck but no vegetation. With poor diving conditions encountered in 2004, the follow up survey allowed for better study due to the improved visibility of up to 7 m. The reefs rise slowly from the seaward side in flattened ridges at both sites and had a good coral cover and diversity, characterized by an abundance of tabular and branching Acroporidae (stag horn corals). The latter are fast growing and the improved coral cover measured above the 2004 estimates in the north probably constitutes reef regeneration, despite the locality not being precisely the same (again, sea conditions precluded this). The reef in the south rose in a wall from 22 m on its SW side in a poorly colonized ridge (Photo Plate 3.12). There is however much evidence of fishing activity on this island.



Photo Plate 3.12: A mixed coral community off the middle inner edge at Nosy Faho.

Banc Malagasy

Banc Malagasy constitutes a submerged bank similar to Banc des Six Metres but is deeper. The reef here comprised very broad and flat spurs with shallow gullies and poor coral cover.

Nosy Dombala

Nosy Dombala is a well-vegetated island with much evidence of fishing activity. A dive was undertaken at its northern point of, this being the side on which the effluent from the proposed discharge site is anticipated to have the greatest effect, if any. The reef here was of slightly higher profile and coral cover than at Banc Malagasy.

Nosy Fonga

Nosy Fonga is little more than a sand bank south of Nosy Dombala. The southernmost dive of the survey was executed on its northern side in the passage between these two islands. It was surmised that effluent from the proposed pipeline reaching this far south would probably move through this gap with tidal exchange. Broken reef similar to that found on the landward side of all the islands was encountered here, but at a higher density, making a representative survey of this reef type possible. Moderate coral cover of good diversity was recorded. As the passage is fairly shallow (8 - 13.5 m), considerable coral bleaching was evident, probably due to reasonable water clarity

(visibility 5 - 7 m) and the tidal exchange of warm surface water. Some giant clownfish anemones were also recorded.

Summary

A synthesis of the significance of these findings is best depicted in an MDS plot (Fig. 3.11). This portrays the gradient in the reefs in terms of coral cover, those having the least cover lying at the top of the plot and those with the most at the bottom. The western and southern sites at Ile aux Prunes constitute “outliers” by virtue of their abundance of the giant anemone, *Heteractis magnifica*, and the hard coral, *Pachyseris speciosa*, respectively. Recif du Sud and the northern and south-eastern sites on Le Grand Recif were the survey sites closest to the harbour mouth and lie at the top of the plot; they are undoubtedly most affected by perturbation, probably mainly turbidity, from this source. The other finding of significance portrayed by the MDS plot is that, apart from Ile aux Prunes W, the five sites depicted as having the greatest coral abundance at the bottom of the plot all lie in the south. The richest, Nosy Faho is the closest to the proposed outfall.

Discussion

A range of representative areas was examined on the reefs in the Tamatave region (Table 3.8). The coral communities appear to be primarily mixed and rather uniform but, with few exceptions, have relatively low biodiversity and cover (Tables 3.6 and 3.8). Scleractinians were prevalent amongst the corals but soft coral encrustations were conspicuous on a shallow wave-cut area. The Acroporidae (stag horn corals) were notably abundant in the few coral-rich areas. Depopulated areas on the better lit reefs were encrusted with coralline algae, these being primary colonizers after reef damage. The reefs thus appear to be stressed and degraded by a combination of factors, the most important of these being turbidity. To a large extent, this turbidity appears to be a natural phenomenon induced by the oceanography in the region. The reefs most affected by turbidity are closest to the harbour. Thus, historically, the reefs have probably always been marginal but the turbidity levels have been exacerbated by anthropogenic factors in recent times. In order of priority, storm damage, fishing damage and ENSO-related bleaching have further added to the poor condition of most of the reefs. Cyclones and the powerful energy of the sea in the region have probably given rise to their generally flat profile.

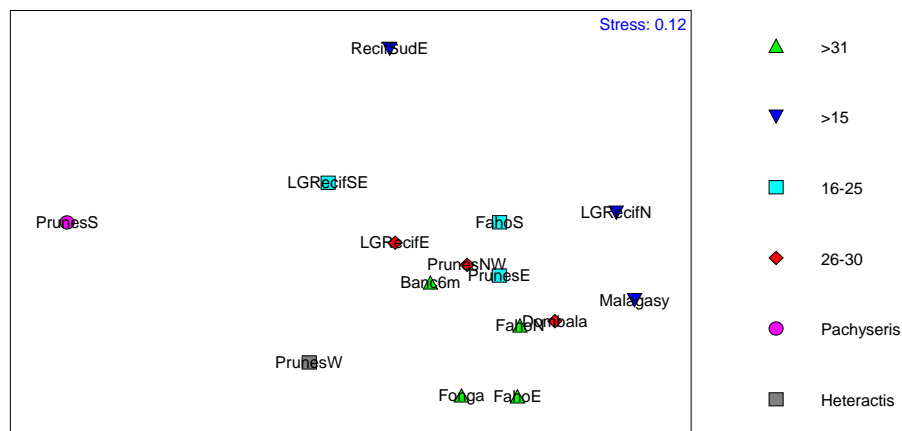


Figure 3.11: MDS ordination of the community structure data obtained from the quadrat images recorded along reef transects at the study sites off Tamatave (Kruskal stress coefficient = 0.12; values assigned to symbols denote percentage coral cover or special attributes).

To place the nature of the Tamatave reefs in context, a comparison will be made with the marginal coral reefs in South Africa. These comprise the southernmost representatives of this fauna in the Western Indian Ocean, yet are richer in terms of biodiversity and reef cover. Some 40 soft coral and 90 hard coral species are found on the South African reefs (Schleyer, 2000); with an average cover generally in excess of 50%. The Tamatave figures (totalling 15 and 64 respectively) are considerably lower, yet these reefs are more tropical and much closer to the Australasian centre of coral development.

Some of the reefs did have impressive coral communities, particularly those around Nosy Faho, which were well-colonized by stag horn corals that are fast-growing but sensitive to perturbation. If the effluent plume from the proposed outfall flows southward, these coral communities will be the most affected by the effluent.

Impact of the outfall on corals

A comprehensive literature search was undertaken to establish the toxicity of the proposed outfall effluent components to corals. This yielded very little. Manganese is generally considered a trace element and corals typically concentrate this material five or more times the naturally occurring concentration in their skeletons (Howard & Brown, 1984, 1986), as do giant clams in their tissues (Khristoforova & Bogdanova, 1981). It is thus unlikely to pose a problem if diluted to the Madagascan limit. No reference is made in the literature to its toxicity on coral reefs so it is presumably fairly benign. The literature revealed little else on the other elements. Most work has been done on the toxicity of copper, which appears to be the most toxic of the metals studied in corals (Reichelt-Brushett and Harrison, 1999), this at levels at least an order of magnitude above

those of the proposed discharge (Alutoin, 2001; Reichelt-Brushett and Harrison, 1999, 2000; Jones, 2004). Hard corals do deal with a certain level of metal contamination by depositing these elements in their skeletal material; this attribute has been used to investigate the history of tailings input from a copper mine into the marine environment in the Philippines (David, 2003) as well as riverine input over time (Bastidas and Garcia, 1999). Other studies have focused on the accumulation of various metals in coral tissues (Esslemont, 1999; Esslemont et al., 2000; Lesley *et al.*, 2003) or their physiological effects on these organisms at concentrations greater than those anticipated in the Ambatovy situation (Gilbert and Guzman, 2001; Nystrom *et al.*, 2001).

Effluents involving gypsum are, however, turbid and corals are sensitive to this form of perturbation. Over 6 000 tonnes of gypsum are discharged per day from a South African plant and this is dissolved in the prevailing current regime by jetting it from pipeline diffusers at $\leq 3.5 \text{ g.l}^{-1}$ (Lord & Geldenhuys, 1986). This discharge appears to be above the concentration proposed for the Ambatovy effluent. Considering the natural levels of turbidity that prevail at sea in the Tamatave region, it is difficult to conceive that the transient turbidity of gypsum at the proposed discharge concentrations will pose a problem if provision is made for its dissolution. Turbidity already poses the greatest problem to the coral communities in the region thus the proposed outfall must have an additional cumulative effect within the region.

Based on these preliminary findings, the coral communities appear to be primarily mixed and rather uniform, with low biodiversity and cover. Soft coral encrustations were conspicuous on a shallow wave-cut area due to their turbidity-resilience. Depopulated areas on the more illuminated reefs were encrusted with coralline algae, these being primary colonizers after reef damage. The reefs thus appear to be stressed and degraded by a combination of factors, the most important of these being turbidity. To a large extent, this turbidity appears to be a natural phenomenon induced by the oceanography in the region. Thus, historically, the reefs have probably always been marginal but the turbidity levels have been exacerbated by anthropogenic factors in recent times. In order of priority, storm damage, fishing damage and ENSO-related bleaching have further added to the poor condition of the reefs. Cyclones and increased wave action in the region have probably given rise to the generally flat profile of the reefs, but all of the factors listed above must be responsible for their poor condition, their low coral cover and poor biodiversity. Between 1966 and 2000, the Toamasina district experienced nine severe cyclones – only two other districts, namely Moramanga and Brickaville were affected by more (Anon. 2002).

3.2.2 ICHTHYOFAUNA

A list of all fish species and/or major groups observed during the surveys is presented in Table 3.9.

Some were identified from fishermen's catches, although the bulk were recorded during the dives described in the section above. Due to poor visibility and the strong surge experienced at most sites; identification of many fish was not possible. While many of

the major groups were represented, e.g. Chaetodontidae, Pomacentridae, Pomacanthidae, Mullidae and Labridae, some are more noticeable either by their absence or poor representation. These include the snappers (Lutjanidae), emperors (Lethrinidae), kingfishes (Carangidae), seabream (Sparidae), rockcods (Serranidae) and rubberlips (Haemulidae). The absence of many of these fish may well be due to the extreme fishing pressure at all the sites that were dived. Most of these species are the larger reef fish, which are susceptible to being captured and are prone to overexploitation. A report on environmental indicators in the Toamasina province stated that the absence of large predatory fish on reefs was identified as a key indicator of high fishing pressure (Anon. 2002). Due to the large swell, reef sites on the seaward side of offshore islands could not be accessed for diving. Furthermore, fishermen's catches could only be inspected on a few occasions. Due to these reasons, this list is by no means complete or definitive of the ichthyofauna in the region and must be considered preliminary.

3.2.3 OTHER MARINE FAUNA

No literature exists on surveys of marine fauna in the region, which need to be conducted. Thus the paucity data, limits the description of the faunal assemblages to visual observations during the 2004 and 2005 surveys conducted for this report.

Although no turtles were seen during any of the dives, several were seen while underway in the boats and one was shown to us by fishermen on Nosy Faho (photo plate 3.13). All were believed to be Green turtles. Marine turtles are regarded a key indicator species in Madagascar, together with dugong (Anon. 2002). Both turtles and dugongs are regarded as Endangered (IUCN, 2004) due to extreme hunting pressure.

Whale and dolphin watching forms a large part of eco-tourism ventures located on the island of Sainte Marie to the north of Tamatave. Two dolphins, possibly Bottlenose were seen in the distance on one of the dive days. Due to their abundance at Sainte Marie it is reasonable to assume that Humpback whales would also be encountered off Tamatave.

3.2.3 FISHERIES

This description of fisheries currently in operation around Tamatave was based on visual observations and interviews with some of the user group participants. An interview with a representative of a major fishing company and processing plant also provided some insight into present and planned (future) operations. The Port of Toamasina is the home of a small commercial fishing fleet that targets several species of prawn. Artisanal fishers also launch from the harbour in small dugouts to fish the nearby Grand Recif. Others launch from the beach to the north of Tamatave and make their way to Ile Aux Prunes. Another user group who are referred to as artisanal by local people have larger boats (Photo Plate 3.14) equipped with outboard engines and they keep their catch refrigerated in large ice boxes. The boat's owner hires a crew to fish for him and their catch is sold to a local dealer. This is most definitely not an artisanal enterprise and for the purposes of this report, this group will be referred to as small scale commercial.

Table 3.9 List of fish species, in phylogenetic order, observed during SCUBA dives and from observations of fishermen's catches at Tamatave.

Family	Species	Common Name
Dasyatidae	Unknown	Stingray
Anguillidae	<i>Anguilla marmorata</i>	Madagascar mottled eel
Ariidae	<i>Ariodes dussumieri</i>	Tropical seacatfish
Belonidae	Unknown	Needlefish
Holocentridae	Unknown	Squirrel & Soldierfish
Aulostomidae	<i>Aulostomus chinensis</i>	Trumpetfish
Serranidae	<i>Epinephelus faveatus</i>	Bisgspot rockcod
	Unknown	Rockcod
Apogonidae	Unknown	Cardinal fish
Lutjanidae	<i>Lutjanus monostigma</i>	Onespot snapper
	<i>Lutjanus sanguineus</i>	Blood snapper
Caesionidae	<i>Caesio caeruleus</i>	Blue-and-gold fusilier
Sparidae	<i>Rhabdosargus sarba</i>	Natal stumpnose
Lethrinidae	<i>Lethrinus nebulosus</i>	Blue emperor
	<i>Lethrinus sanguineus</i>	Cutthroat emperor
Kyphosidae	<i>Kyphosus cinerascens</i>	Blue chub
Mullidae	<i>Mulloidides flavolineatus</i>	Yellowstripe goatfish
	<i>Parupeneus bifasciatus</i>	Two-saddle goatfish
	<i>Parupeneus indicus</i>	Indian goatfish
	<i>Parupeneus macronema</i>	Band-dot goatfish
	Unknown (several species)	Goatfish
Pomacanthidae	<i>Apothemichthys trimaculatus</i>	Threespot angelfish
	<i>Centropyge acanthops</i>	Jumping bean
	<i>Centropyge multispinis</i>	Dusky cherub
	<i>Pomacanthus semicirculatus</i>	Semicircle angelfish
	Unknown	Angelfish
Chaetodontidae	<i>Chaetodon blackburnii</i>	Browburnie
	<i>Chaetodon dolosus</i>	Blackedged butterflyfish
	<i>Chaetodon falcula</i>	Saddled butterflyfish
	<i>Chaetodon guttatissimus</i>	Georgious gussy
	<i>Chaetodon lunula</i>	Halfmoon butterflyfish
	<i>Chaetodon meyeri</i>	Maypole butterflyfish
	<i>Chaetodon trifascialis</i>	Rightangle butterflyfish
	<i>Chaetodon trifasciatus</i>	Purple butterflyfish
	<i>Chaetodon unimaculatus</i>	Limespot butterflyfish
	<i>Chaetodon vagabundus</i>	Vagabond butterflyfish
	<i>Forcipiger flavissimus</i>	Longnose butterflyfish
	<i>Heniochus acuminatus</i>	Coachman
Echeneidae	<i>Echeneis naucrates</i>	Shark remora
Cirrhitidae	<i>Paracirrhites arcatus</i>	Horseshoe hawkfish

Family	Species	Common Name
Pomacentridae	<i>Abudefduf notatus</i>	Dusky damsel
	<i>Abudefduf sordidus</i>	Spot damsel
	<i>Abudefduf vaigiensis</i>	Sergeant major
	<i>Abudefduf</i> sp.	Damselfish
	<i>Amphiprion allardi</i>	Twobar anemonefish
	<i>Chromis dimidiata</i>	Chocolate dip
	<i>Chromis nigrura</i>	Blacktail chromis
	<i>Chromis ternatensis</i>	Golden chromis
	<i>Chromis</i> sp.	Damselfish
	<i>Dascyllus trimaculatus</i>	Domino
	<i>Plectroglyphidodon leucozonus</i>	Sash damsel
	<i>Pomacentrus caeruleus</i>	Blue pete
Labridae	<i>Bodianus</i> sp.	Hogfish
	<i>Coris</i> sp.	Coris
	<i>Gomphosus caeruleus</i>	Birdfish
	<i>Halichoeres hortulans</i>	Checkerboard wrasse
	<i>Halichoeres</i> (several species)	Wrasse
	<i>Labroides dimidiatus</i>	Bluestreak cleaner wrasse
	<i>Thalassoma hebraicum</i>	Goldbar wrasse
	Unknown (several species)	Wrasse
Scaridae	<i>Scarus cyanescens</i>	Blue humphead wrasse
	Unknown (several species)	Parrotfish
Mugilidae	Unknown	Mullet
Acanthuridae	<i>Acanthurus lineatus</i>	Bluebanded surgeon
	<i>Acanthurus triostegus</i>	Convict surgeon
	<i>Acanthurus</i> sp.	Surgeonfish
	<i>Ctenochaetus</i> sp.	Bristletooth
	<i>Zebrasoma veliferum</i>	Sailfin tang
	<i>Naso lituratus</i>	Orange-spine unicorn
	<i>Naso</i> (several species)	Unicornfish
Zanclidae	<i>Zanclus canescens</i>	Moorish idol
Siganidae	<i>Siganus sutor</i>	Whitespotted rabbitfish
Balistidae	Unknown	Triggerfish
Tetraodontidae	<i>Arothron hispidus</i>	Whitespotted blaasop
	<i>Arothron immaculatus</i>	Blackedged blaasop
	<i>Canthigaster amboinensis</i>	Spotted toby
	<i>Canthigaster valentini</i>	Model toby
	<i>Canthigaster</i> sp.	Toby



Photo Plate 3.13: The remains of a green turtle caught by fishermen on Nosy Faho.



Photo Plate 3.14: A typical boat used by the small scale commercial fishing sector. The large ice boxes are clearly visible.

3.5.1 COMMERCIAL PRAWN FISHERY

A total of seven freezer trawlers are based at Tamatave and they fish along the entire Madagascar coastline. Their primary target species, and those comprising the majority of the catch are *Penaeus indicus* (white prawn) and *Metapenaeus monoceros* (speckled prawn). The remainder of the catch is made up of *P. monodon* (tiger prawn), *P. japonicus* (ginger prawn) and *P. semisulcatus* (green prawn). In addition a mixed by-catch of fish (composition unknown) is also retained. The annual catch of prawn is in the region of 600 tonnes, and this is accompanied by up to 1 500 tonnes of fish by-catch. All prawns are exported to Europe or the United Kingdom, with the fish by-catch being sold to local hotels and restaurants or to the general public through a retail outlet in town. At present there are approximately 300 local people employed by Réfrigépêche.

3.5.2 SMALL SCALE COMMERCIAL FISHERY

These operators use locally made boats between six and seven meters long fitted with single outboard engines of up to 40 hp. The exact number of boats is not clear but there appear to be at least five in operation. They carry two large fiberglass ice boxes that are used to keep the catch fresh for the period they are away at sea (Photo Plates 3.14 and 3.15). The major area utilized by these fishers is to the south of the port, in the vicinity of the proposed outfall. Boats, with a crew of between 6 and 10 men, travel to Nosy Faho, Nosy Dombala and Nosy Fonga and stay on site for 5 to 7 days or until their ice boxes are full. All manner of gear types are used, namely handline, gillnet, cast net, spear and traps and there is no selectivity, i.e. if it can be caught it is killed. The major catch appears to be octopus (most likely *Octopus cyanea*), which is caught in traps that also occasionally account for lobster. Larger fish species such as snappers, rockcods, emperors, unicorns, sea bream, barbel and stingrays are kept on ice and sold when they return to port. Smaller species are eaten on site. Turtles are also caught in the nets on occasion. The catch is sold to a local distributor where prices per kg range from 5 000 MGF for octopus, 35 000 MGF for lobster, 15 000 MGF for selected species such as blood snapper and rockcod and 7 000MGF for other fish species.

3.5.3 ARTISINAL FISHERY

Numerous small dugout craft operate from the harbour and along the coastline to the north and south of the harbour. These operators paddle their boats to Le Grand Recif, Ile Aux Prunes and Nosy Faho whenever conditions permit or they fish in calmer waters close to shore and within the confines of the port (Figure 3.12). Those fishing the area around Nosy Faho come from the villages near the proposed outfall site and launch from the mouth of the Ivondro estuary. Unlike the small scale commercial operators, these fishers don't stay out longer than a day. Their catch provides food for their household or village, with excess being sold or traded for other essential goods. Some lay down small mesh gillnets (mesh size between 25 and 43 mm) and traps for octopus, while other fish with handline. Those operating in shallow waters around the islands use spears and cast nets. All marine creatures that can be caught or eaten are targeted, including octopus and small fish such as wrasses, rabbitfish and surgeons (Table 3.5).



Photo Plate 3.15: An icebox on a vessel at Nosy Faho with a days catch, which includes emperor snapper, sea barbel, tiger rockcod and unicorn fish.

A few boats (3 or 4) operate small mesh beach seine nets along the shoreline inside the harbour. Their catch is meager, and comprises mostly few small fish. On occasion they may catch prawns, but this is a rarity given the levels of pollution on the area where they fish.

The Ivondro estuary and associated waterways are utilized by local communities. The majority of their fishing activities occur on this system, as sea conditions do not allow them to launch through the mouth too often. Large gillnets measuring 100 m (Photo Plate 3.18) are used extensively as blocknets that are placed across narrow parts of the channel. Traps are also baited and used to catch crabs (most likely *Scylla* sp.; Photo Plate 3.17). Large sections of the estuary and the adjoining lakes are criss-crossed with traps (Photo Plate 3.30) that are extremely effective at catching most species. These traps are serviced at low tide where fish are netted or speared in the shallow water. During interviews with some local villagers, it was determined that mullet (*Mugilidae*) comprise the major catch, except in June when large catches of eel are made (most likely *Anguilla marmorata*). No prawns are caught in the system. The catch is used to feed the community within the village, however, when large catches are experienced, the excess is taken to Tamatave and sold.



Photo Plate 3.16: The large gillnets used by artisanal fishermen in the Ivondro estuary and associated lakes.

3.5.4 FUTURE PLANS FOR ADDITIONAL FISHERIES

Two new 16 m fishing boats have been commissioned by Réfrigépêche and will participate in a new fishery that targets reef fish using handlines. These boats will operate in local waters and target fish on the deeper reefs not accessed by artisanal or small scale commercial operators. A list of desired target species was provided and included all emperor (Lethrinidae), snapper (Lutjanidae) and rockcod (Serranidae) species that may be found in the area. None of this catch is for the local market and all is destined for export to Reunion. Additional plans include further empowering the small scale commercial fleet by supplying them with ice and buying and processing their catch – a practice that already appears to be taking place. There appears to be an agreement between the commercial fleet and the other user groups that the waters to the south of Tamatave, between the Port and the offshore islands of Nosy Faho, Nosy Dombala and Nosy Fonga have been set aside for the artisanal fishers. These would include the bona fide artisanal users as well as the small scale commercial fishers. A concern expressed by Mr. Barcelo of Réfrigépêche was that the pipeline may pollute those waters and hence affect the fishery.



Photo Plate 3.17: Traps that are used to catch crabs in the Pangalanes Canal and Ivondro estuary.



Photo Plate 3.18: A barricade of traps across the entrance to Lake Ambinanikoro near the Ivondro estuary mouth.

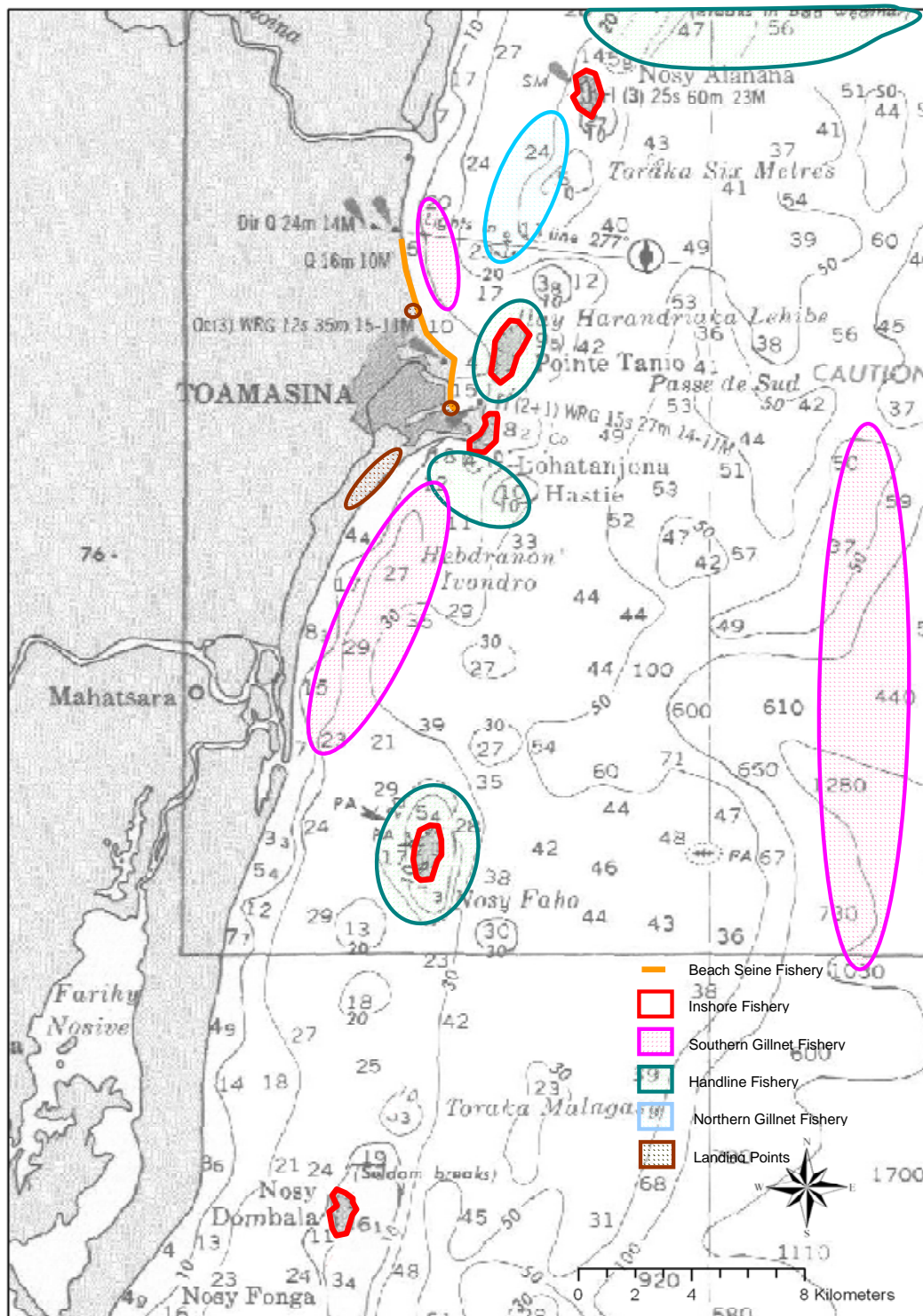


Figure 3.12: Map outlining key fishing areas around Toamasina.

CHAPTER 4: EFFLUENT PLUME DILUTION AND SETTLING MODELLING

4.1 DILUTION MODELLING

The process of dilution commences the moment effluent is discharged from a port of a diffuser. This is referred to as the initial dilution stage. In the case of a buoyant effluent plume, where the effluent density is less than the surrounding ambient water density - as is the case for the proposed Ambatovy effluent - the plume will rise rapidly to the surface and in the process mix with surrounding sea water.

As the effluent plume moves away from the point of discharge the effluent becomes more diluted and the nearfield mixing is considered to terminate either when the mixed effluent reaches the surface or when the effluent becomes stable at an intermediate water depth and levels out parallel to the surface (WRC, 1992).

Dilution subsequent to this process is referred to as secondary or farfield dilution and involves the physical spreading of the effluent into the surrounding sea water by diffusion. The process is strongly influenced by prevailing ocean currents, with further vertical mixing induced by the local wind climate.

4.2 EFFLUENT DESIGN CRITERIA

For the purposes of dilution modelling, the following effluent design criteria have been used:

4.2.1 Effluent Characteristics

The effluent characteristics as provided to PRDW by Dynatec were used for dilution modelling. From these effluent characteristics, the specific gravity of the effluent is expected to be less than 1.003, which is less than the specific gravity of seawater (1.023). Dilution modelling has therefore been based on a buoyant effluent with a density equivalent to fresh water, i.e. 1000 kg/ m³.

4.2.2 Water Quality Limits

Dilution requirements have been determined by considering the outfall effluent characteristics and the Madagascar water quality limits (refer to Chapter 2). The pollutants that have the highest dilution requirements are summarized in Table 4.1.

Table 4.1: Dilution requirements based in the Madagascan water limits.

Pollutant	Effluent Concentration (mg/l)	Madagascar Limit(mg/l)	Dilution Required
Total Suspended Solids, TSS	100	60	2
Manganese	115	5	23
Sulphate, S(SO ₄)	4750	250	19

From Table 4.1 it is evident that when using the Madagascar water quality limits, the critical pollutant is Manganese, requiring a dilution of 23 times. Where Madagascar water quality limits have not been provided for pollutants, international standards were applied as indicated in Chapter 2 and in Volume F, Section 3.9.

All effluent constituents are conservative, i.e. concentrations will not be reduced by decay due to die-off of micro-organisms or chemical reactions and thus the critical value for acceptable dilution of 25 is used in this report.

4.3 SITE CHARACTERISTICS

4.3.1 Water Depth at Point of Discharge

The proposed outfall location is shown in Figure 4.1 for distances extending 425 m, 975 m and 2075 m from the nearest shoreline bank to the centre point of the diffuser line. Water depths at these locations are approximately 10 m, 20 m and 25 m respectively. The study brief was to investigate which of these discharge sites would satisfy the water quality criterion adopted for the study.

4.3.2 Ambient Current Conditions

Current measurements around the outfall site are limited to March/April 1998 (Summer) and September/October 1998 (Winter) as extracted from the Océanide (2005) report. Current meters were fixed at points located at 18°10'54'' S, 49°23'58''E (south of Toamasina) at depths of 7 and 19 m with the total seawater depth reaching 22m. Summer measurements were taken from 08/03/98 until 07/04/98. During the winter, readings were taken from 08/08/98 until 09/09/98. The surface current meter did not function during winter.

Table 4.2 tabulates the occurrence statistics as a function of current speed and current direction (direction coming from) as shown in Océanide (2005).

Table 4.2: Characteristic current measurements for the regions (Oceánide, 2005)

	Summer		Winter
Water Depth (m)	- 7	- 19	- 19
Max (m/s)	0.29	0.26	0.35
Min (m/s)	0	0	0
Mean (m/s)	0.069	0.03	0.04
Deviation (m/s)	0.042	0.031	0.04

In this study far-field modelling has been carried out for a number of different current speeds i.e. 0.05 m/s, 0.1 m/s, 0.5 m/s and 1.0 m/s. These current speeds were applied uniformly through the water column for all conditions tested. Current directions (direction coming from), of 45 deg True North (TN); 255 deg TN; and 345 deg TN were selected for the modelling exercise.

4.3.3. Local Wind Conditions

Annual wind statistics were extracted from the data analysis report for Tamatave (Oceánide, 2005). Based on this data the wind climate in the Tamatave region is shown to be dominated by winds originating between the Easterly and the South Easterly direction sectors. Wind conditions from this sector account for 48% of the total data set. The annual average wind speed is given as 7.3 m/s with a standard deviation of 3.2 m/s.

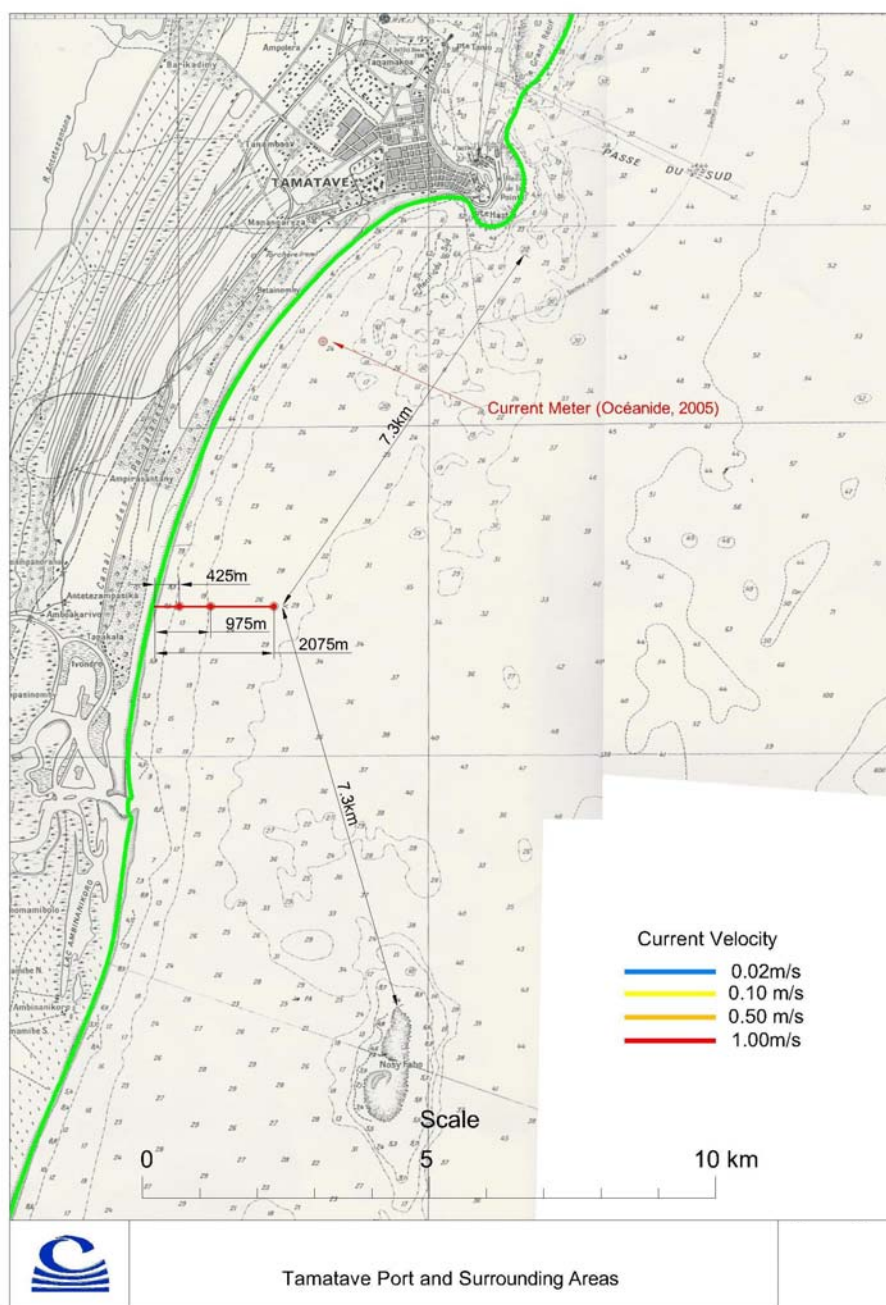


Figure 4.1: Propose locality of outfall pipeline, with an indication of the three possible distances used in the plume models.

4.3.4 Local Wave Conditions

The wave data in the form of an occurrence table, as extracted from Oceánide (2005), is presented as an exceedance graph is presented in Figure 4.2.

4.3.5 Temperature and Density

The effect of density stratification on effluent dilution has been included by assuming temperatures and densities of 24°C (1023.7 kg/m³), 23°C (1023.9 kg/m³) and 22.5°C (1024.1 kg/m³) for 10 m, 20 m and 25 m water depth respectively. The surface temperature and density is assumed to be 25 °C and 1023.4 kg/m³, respectively.

4.4 DIFFUSER DESIGN CHARACTERISTICS

4.4.1 Outfall Hydraulic Characteristics

The diffuser system used in this study has been designed to handle a maximum discharge flow of 4000 m³/hr (1.11 m³/s). Tests have been carried out to model discharge flows as low as 2000 m³/hr (0.55 m³/s).

4.4.2 Diffuser Arrangement

The selection of a suitable preliminary diffuser arrangement has been based on limiting the head loss for the diffuser while ensuring that the average velocities in both the main pipe and the ports exceed 0.7 m/s for all flow conditions. Based on the results from PRDW (2004) a diffuser port diameter of 0.2 m for all flow conditions has been used. In addition, the diffuser ports have been orientated to discharge horizontally via 90 degree elbows.

The preliminary diffuser arrangement details used for the dilution modelling are as follows (Figure 4.3):

Diffuser Pipe	750 mm nominal diameter, 150 m long
Diffuser Ports	200 mm nominal diameter, 16 No.

With a total of 16 diffuser ports, at a spacing of 10 m apart (alternating), the average flow rate for each port varied between 34 and 69 l/s and the port velocities between 1.1 m/s and 2.2 m/s.

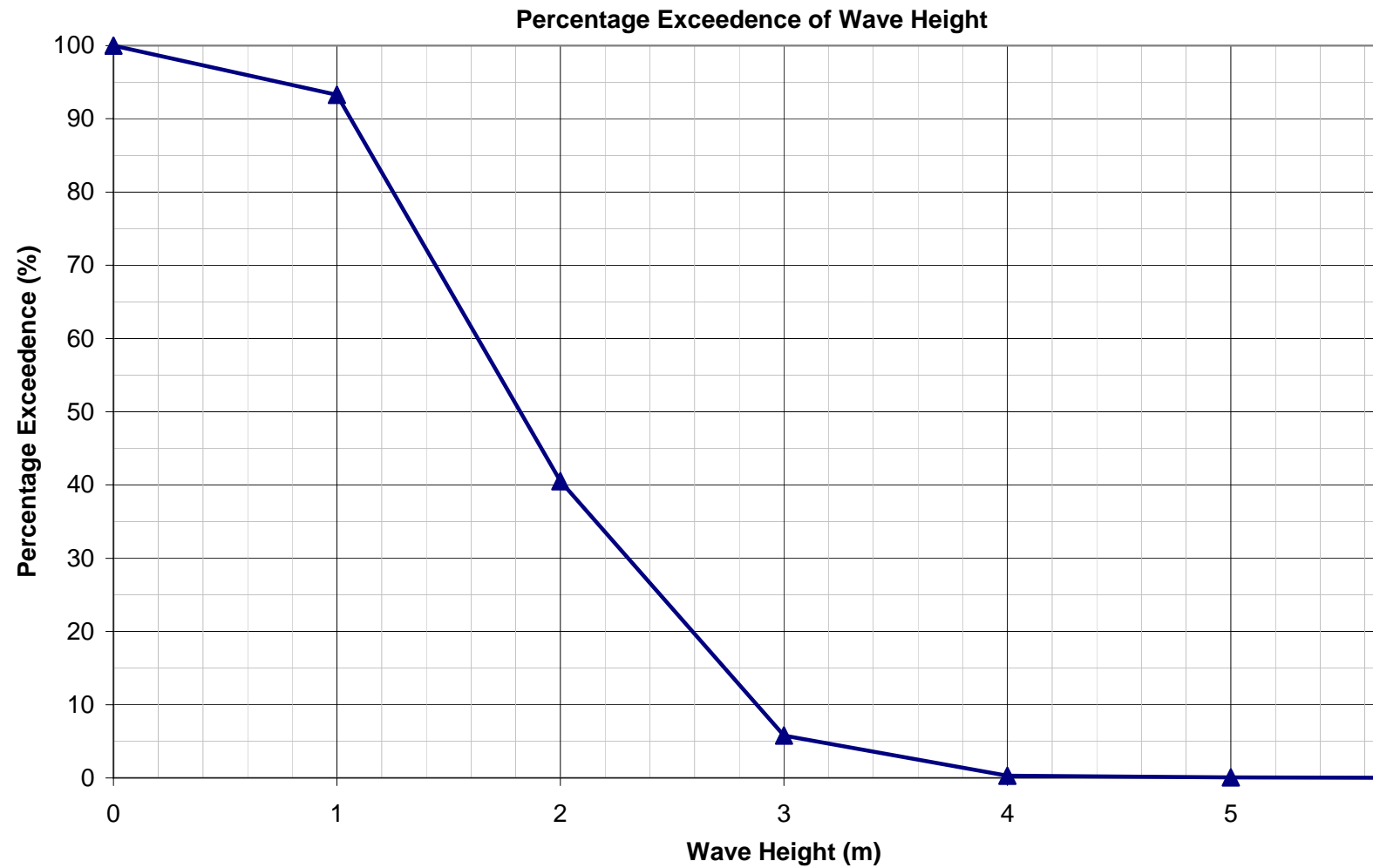


Figure 4.2: The percentage exceedance curve based on wave height data from Océanide 2005

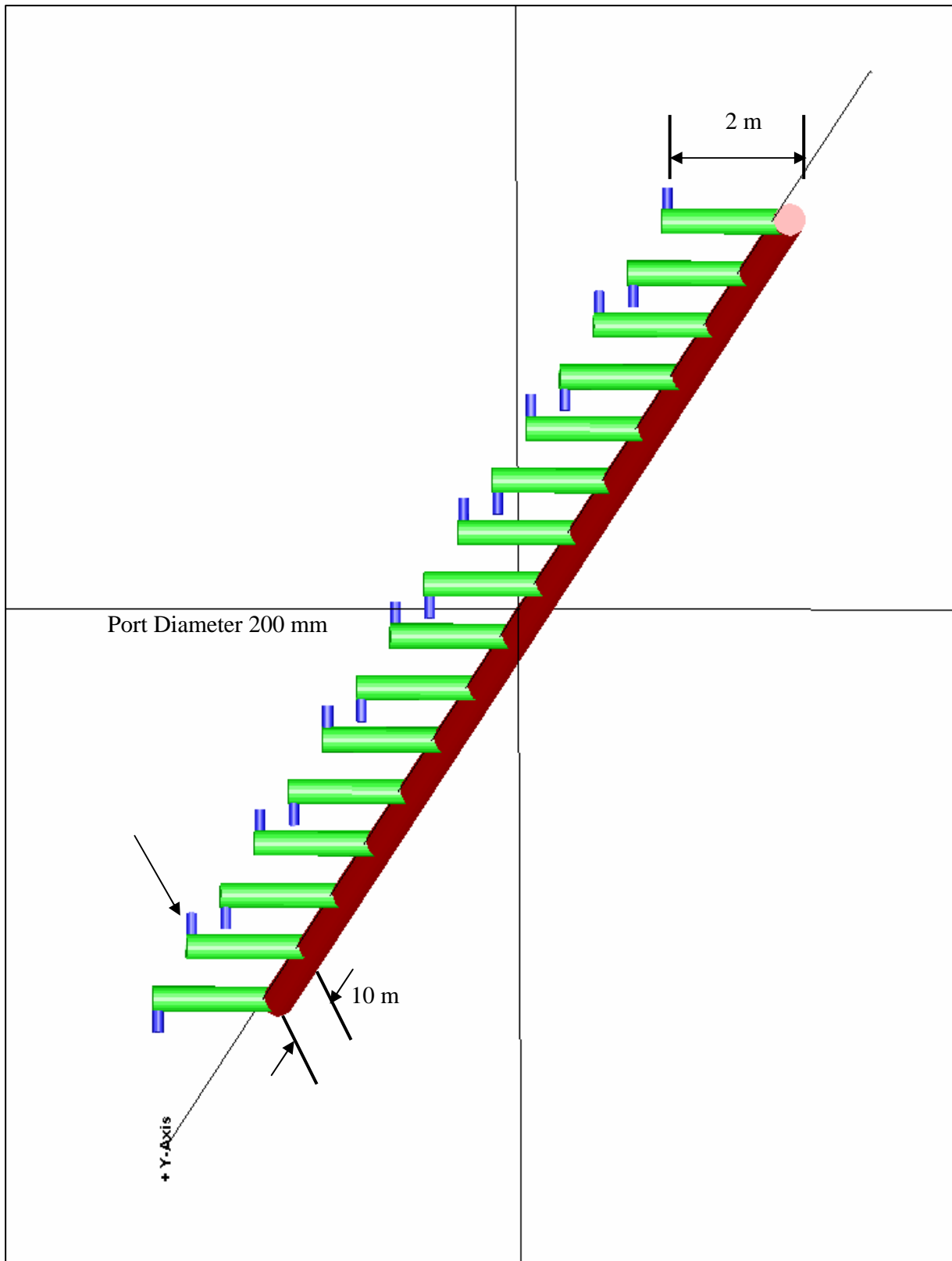


Figure 4.3: A three dimensional generated view of the proposed diffuser system.

4.5 CORMIX MODELLING

Farfield dilution modelling has been conducted using the Cornell Mixing Zone Expert System (CORMIX, version 4.3 GT); in particular the CORMIX2 model for submerged multiport diffuser discharges.

CORMIX is a software system used for the analysis, prediction and design of discharges into diverse water bodies. The major emphasis is on the geometry and dilution characteristics of the initial mixing zone, with the model also predicting the behaviour of the effluent plume at larger distances from the point of discharge.

Input Parameters

The following input parameters have been used in the setup of CORMIX modelling test conditions:

Ambient Conditions

Water depth	25 m, 20 m, 10 m (i.e. 3 cases)
Current (Uniform Distribution)	0.02 m/s, 0.1 m/s, 0.5 m/s, 1.0 m/s
Friction Factor (Darcy-Weisbach)	0.025
Wind Speed	0 m/s, 3m/s, 4m/s and 10 m/s
Seawater Temperature	22.5 °C at 25 m, 23 °C at 20 m, 24 °C at 10 m
Seawater Density	1024.1 kg/m ³ at 25 m, 1023.9 kg/m ³ at 20 m, 1023.7 at 10 m
Seawater Surface Temperature	25 °C (at 0 m)
Seawater Surface Density	1023.4 kg/m ³
Seawater Salinity	35 ppt

Effluent Characteristics

Total flow	1.11 m ³ /s, 0.88 m ³ /s, 0.55 m ³ /s
Effluent salinity	0
Effluent Density	1000 kg/m ³
Effluent temperature	25 °C
Effluent Concentration	100 %

Diffuser Characteristics

Diffuser Length	150 m
Port elevation	2 m above seabed
Port diameter	0.2 m
Contraction coefficient	0.61 (conservative value)
Number of ports	16
Port spacing	10 m

4.5.1 Modelling Current Direction

A limitation of the CORMIX model is that the current direction is always parallel to the model bank boundary. In order to investigate the affect an oblique current has on the spreading of the plume, the diffuser line was orientated at a direction perpendicular

to the desired current direction. Table 4.4 shows the input variables required for setting up the diffuser geometry for the three current directions selected.

Table 4.3: Diffuser geometry requirements for the 3 current direction scenarios.

Water Depth [m]	10	20	25	10	20	25	10	20	25
Current Direction [deg]	45°TN			255°TN			345°TN		
Shore Bank	Right			Left			Right		
Gamma [deg] γ	45			15			105		
Theta [deg] θ	0			0			0		
Sigma [deg] σ	315			285			15		
Beta [deg] β	90			90			90		
Diffuser Start – Ds [m]	372	922	2022	406	956	2056	353	903	2003
Diffuser End – De [m]	478	1028	2128	444	994	2094	497	1047	2147

Where:

- γ diffuser alignment angle
- θ vertical angle of discharge
- σ horizontal angle of discharge
- β relative orientation angle measured from the port centreline
- Ds distance from shore bank to first port
- De straight line distance from shore bank to last port

4.5.2 Water Quality Criterion

The dilution results discussed in this section will be given as a function of 5 input variables:

Water depth
 Discharge Rate (Q)
 Current speed
 Current direction
 Wind speed (Ws)

The water quality dilution criterion adopted in this study is a dilution of 25 times. This criterion is to be reached before the plume spreads and reaches the closet shoreline bank.

The three water depths are:

- 10 m water depth at 425 m from shoreline
- 20 m water depth at 975 m from shoreline
- 25 m water depth at 2075 m from shoreline

4.6 CORMIX RESULTS

4.6.1 Presentation of Results

Dilution (S) is defined as the ratio of initial concentration (at the discharge port) to the concentration at a given location away from the port. For buoyant plumes Cormix presents the dilution results in two forms, which are dependant on the mixing regime. For the nearfield mixing regime, dilution (S_c) is presented as the minimum centreline dilution for the plume while for the farfield regime the results are presented as flux-averaged dilutions (S_f). The ratio between S_f/S_c for a multiport diffuser discharge is 1.3.

In this report the flux averaged results will be presented as a function of centreline chainage from the diffuser centre.

4.6.2 EFFECT OF WATER DEPTH

The average dilution results for a diffuser line at 10 m, 20 and 25 m water depth will be presented in this section. The results will be shown for five scenarios at two discharge rates (Q) and four wind speeds (Ws) for varying current speeds (4) and current directions (3). The conditions are:

1. Condition 1 - $Q = 4000 \text{ m}^3/\text{h}$ and $W_s = 0 \text{ m/s}$
2. Condition 2 - $Q = 2000 \text{ m}^3/\text{h}$ and $W_s = 0 \text{ m/s}$
3. Condition 3 - $Q = 4000 \text{ m}^3/\text{h}$ and $W_s = 3 \text{ m/s}$
4. Condition 4 - $Q = 4000 \text{ m}^3/\text{h}$ and $W_s = 4 \text{ m/s}$
5. Condition 5 - $Q = 4000 \text{ m}^3/\text{h}$ and $W_s = 10 \text{ m/s}$

Outfall at 10 m Water Depth

Table B.1 in (Appendix 4) presents the average dilution results for a diffuser line at 10 m water depth, for the above five discharge rates and wind speed combinations, for an ambient current speed of 0.02 m/s.

The dilution results as a function of the remaining three current speeds (0.1 m/s, 0.5 m/s and 1 m/s) and current directions (45° TN, 255° TN and 355° TN) are given in Tables B.2 to B.4 (Appendix 4).

The results from Tables B.1 to B.4 are summarized in Table 4.5. When considering the most conservative current condition (0.02 m/s) the required water quality criterion is not satisfied for Conditions 1 and 2. In order for this criterion to be satisfied a minimum wind speed of 3 m/s is required in conjunction with an ambient current of 0.02 m/s.

Table 4.4: Summary of dilutions results for diffuser depth of 10 m.

	10 m Water Depth (425 m from centerline to shore)											
Current Direction	45° TN				255° TN				345° TN			
Current Speed (m/s)	0.02	0.10	0.50	1.00	0.02	0.10	0.50	1.00	0.02	0.10	0.50	1.00
Condition 1 Q = 4000 m ³ /h and Ws = 0 m/s	X	✓	✓	✓	X	✓	✓	✓	X	✓	✓	✓
Condition 2 Q = 2000 m ³ /h and Ws = 0 m/s	X	✓	✓	✓	X	✓	✓	✓	X	✓	✓	✓
Condition 3 Q = 4000 m ³ /h and Ws = 3 m/s	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Condition 4 Q = 4000 m ³ /h and Ws = 4 m/s	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Condition 5 Q = 4000 m ³ /h and Ws = 10 m/s	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

The dilution results presented for Condition 4 (a discharge rate of 4000 m³/h and a wind speed of 4 m/s) are shown graphically in Figure 4.4 (45 deg TN), Figure 4.5 (255 deg TN) and Figure 4.6 (345 deg TN). Each figure consists of 4 semi-circular rings drawn at fixed radial offsets from the diffuser centre point. These offsets are 425 m, 925 m, 2075 m and correspond to the distances measured from the diffuser to shore, at depths of 10, 20 and 25 m.

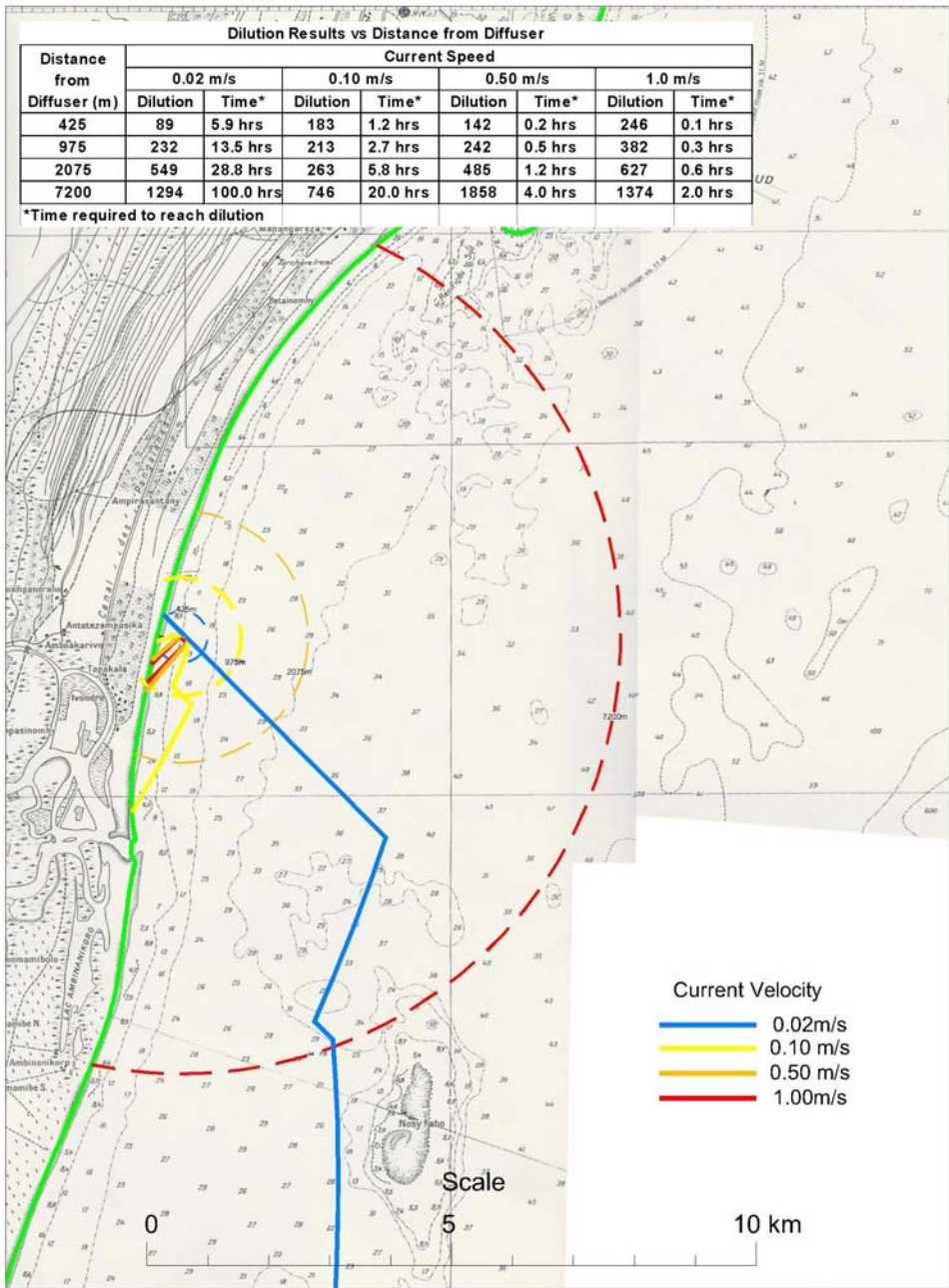


Figure 4.4: PRDW Plume analysis results for the 10 m water depth at a discharge rate of 4000 m³/hr, current direct 45° and wind speed 4m/s scenario.

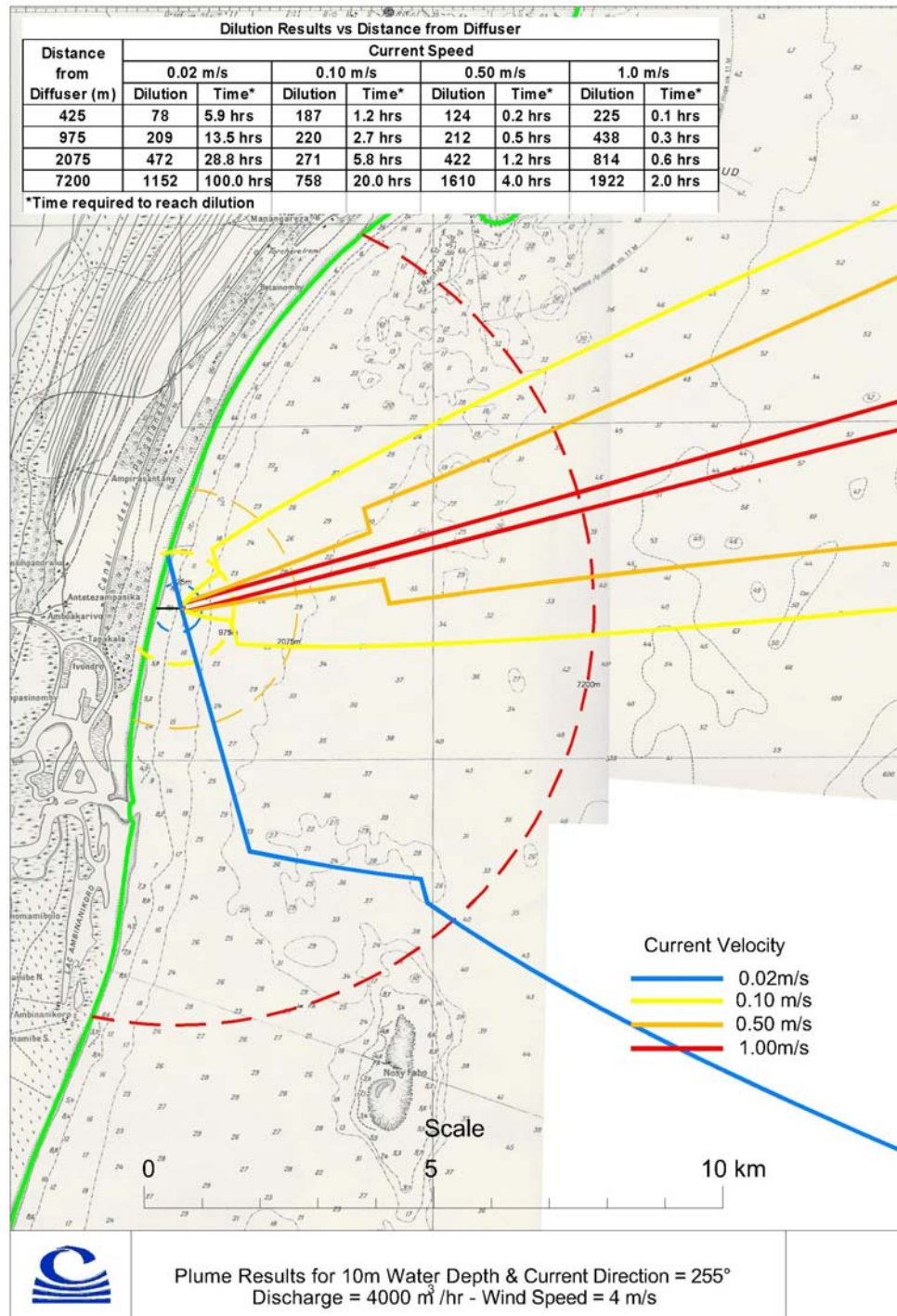
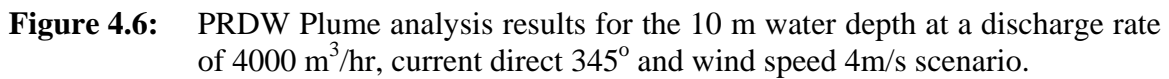


Figure 4.5: PRDW Plume analysis results for the 10 m water depth at a discharge rate of 4000 m³/hr, current direct 255° and wind speed 4m/s scenario.



An offset of 7300 m is also shown and indicates the distance to Nosy Faho in the south and Point Hastie to the north (Figure 4.1). The spreading envelope over which a plume disperses is shown for each current speed modeled, i.e. 0.02 m/s, 0.1 m/s, 0.5 m/s and 1 m/s. A table indicating the dilution results at these offsets and current speeds is provided on each figure. Also shown in this table is the estimated travel time (hours) for a plume to reach these specific offset distances.

Outfall at 20 m Water Depth

Table B.5 (Appendix 4), presents the dilution results (at an ambient current speed of 0.02 m/s) for a diffuser line at 20 m water depth, for the same five discharge rates and wind speed combinations.

The dilution results as a function of the remaining three current speeds (0.1 m/s, 0.5 m/s and 1 m/s) and current directions (45° TN, 255° TN and 355° TN) are given in Tables B.6 to B.8 (Appendix 4).

The results from Tables B.5 to B.8 are summarized in Table 4.6. The results indicate that the water quality criterion is satisfied for all 5 conditions modeled at all current speeds and wind speed combinations.

Table 4.5: Summary of dilutions results for diffuser depth of 20 m.

	20 m Water Depth (975 m from centerline to shore)											
Current Direction	45° TN				255° TN				345° TN			
Current Speed (m/s)	0.02	0.10	0.50	1.00	0.02	0.10	0.50	1.00	0.02	0.10	0.50	1.00
Condition 1 Q = 4000 m ³ /h and Ws = 0 m/s	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Condition 2 Q = 2000 m ³ /h and Ws = 0 m/s	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Condition 3 Q = 4000 m ³ /h and Ws = 3 m/s	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Condition 4 Q = 4000 m ³ /h and Ws = 4 m/s	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Condition 5 Q = 4000 m ³ /h and Ws = 10 m/s	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

The dilution results presented in Tables B5 to B8 for Condition 4 (a discharge rate of 4000 m³/h and a wind speed of 4m/s) are shown graphically in Figure 4.7 (45 deg TN), Figure 4.8 (255 deg TN) and Figure 4.9 (345 deg TN).

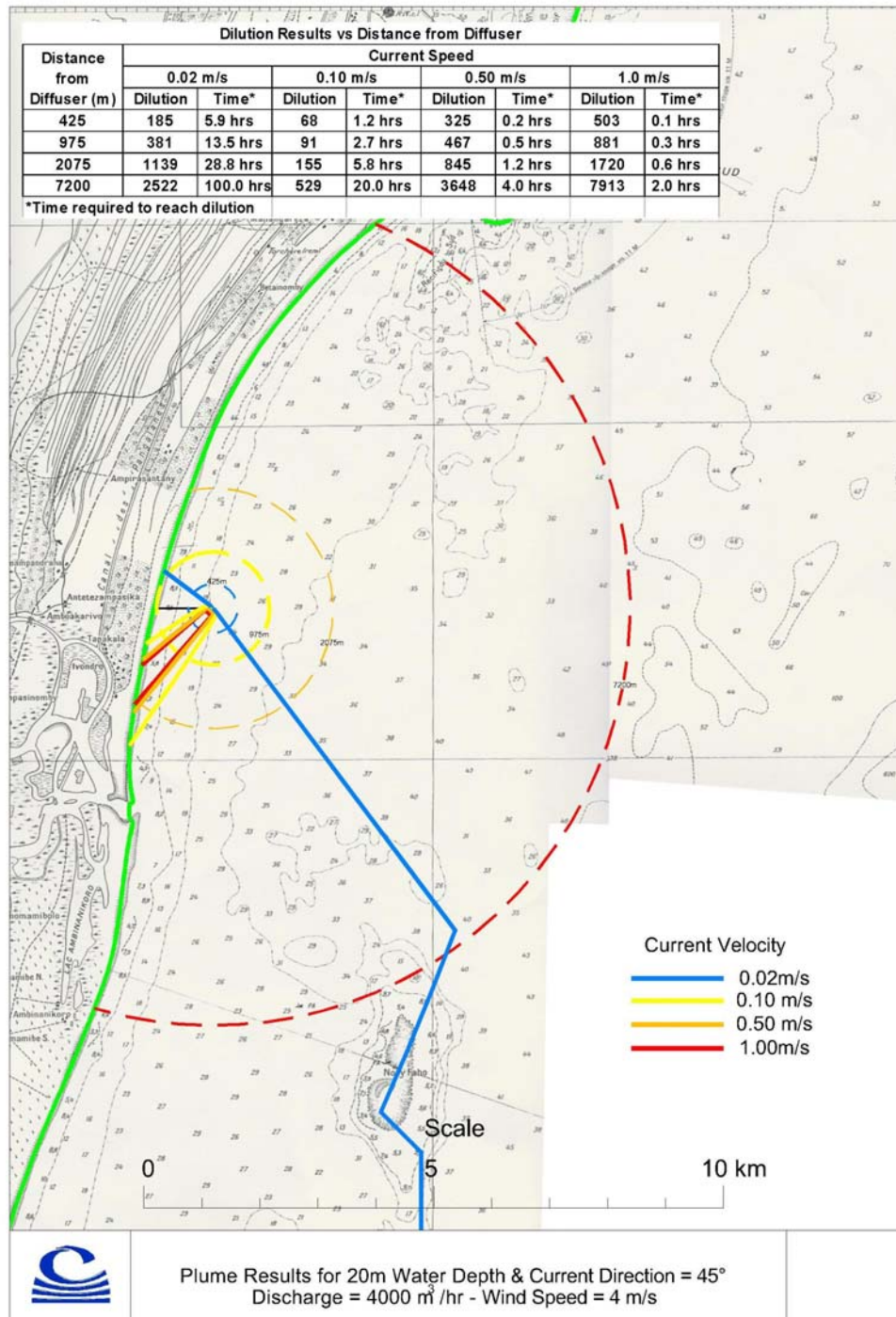
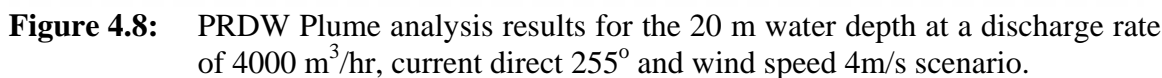


Figure 4.7: PRDW Plume analysis results for the 20 m water depth at a discharge rate of 4000 m³/hr, current direct 45° and wind speed 4 m/s scenario.



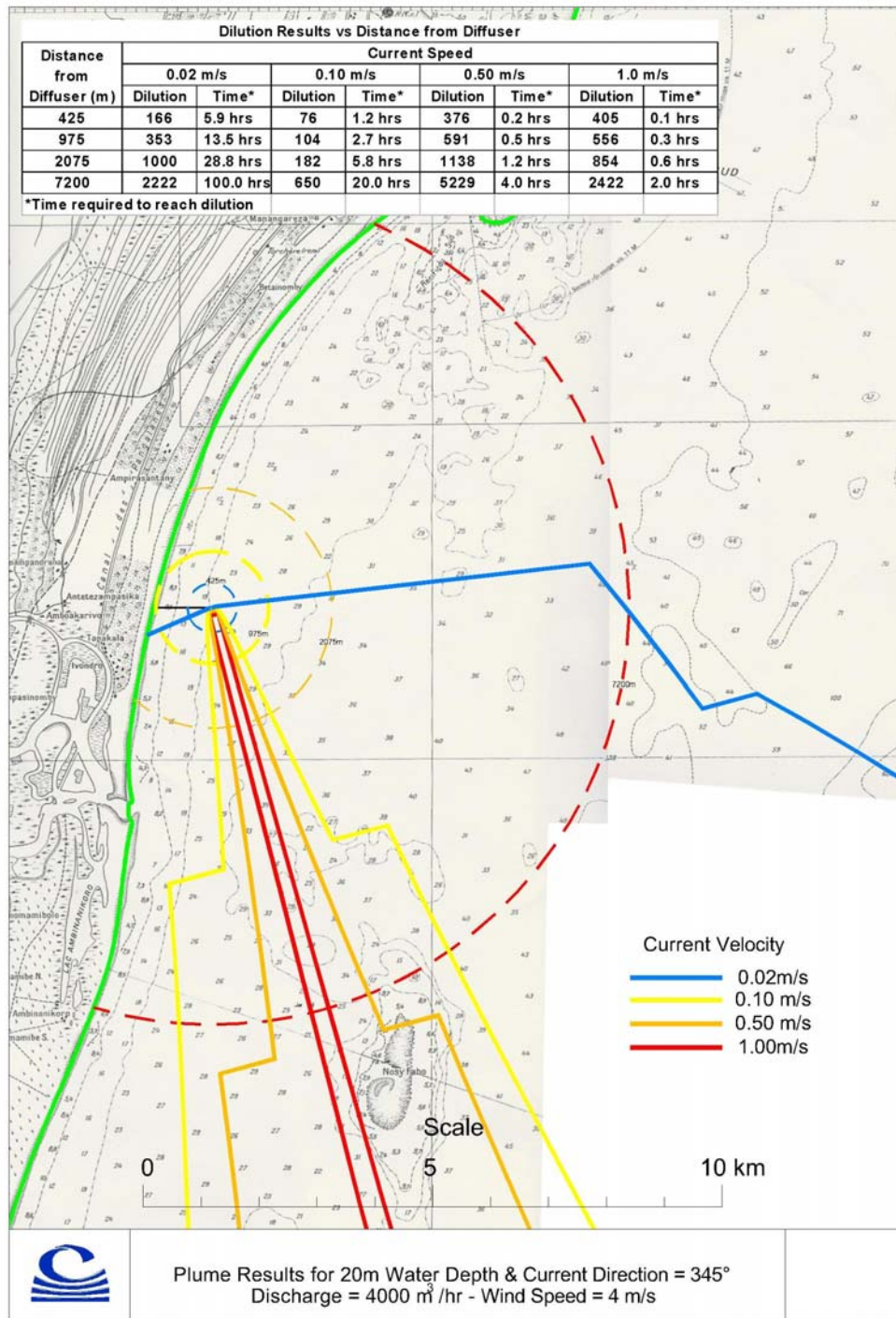


Figure 4.9: PRDW Plume analysis results for the 20 m water depth at a discharge rate of 4000 m³/hr, current direct 345° and wind speed 4m/s scenario.

Outfall at 25 m Water Depth

Table B.9 (Appendix 4) presents the dilution results (at an ambient current speed of 0.02 m/s) for a diffuser line at 25 m water depth, for the same five discharge rates and wind speed combinations given in Section 5.3.2.

The dilution results as a function of the remaining three current speeds (0.1 m/s, 0.5 m/s and 1 m/s) and current directions (45° TN, 255° TN and 355° TN) are given in Tables B.10 to B.12.

The results from Tables B.9 to B.12 are summarized in Table 4.7. The results indicate that the water quality criterion is satisfied for all 5 conditions modelled at all current speeds and wind speed combinations.

Table 4.6: Summary of dilutions results for diffuser depth of 25 m.

	25 m Water Depth (2075 m from centerline to shore)											
Current Direction	45° TN				255° TN				345° TN			
Current Speed (m/s)	0.02	0.10	0.50	1.00	0.02	0.10	0.50	1.00	0.02	0.10	0.50	1.00
Condition 1 Q = 4000 m ³ /h and Ws = 0 m/s	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Condition 2 Q = 2000 m ³ /h and Ws = 0 m/s	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Condition 3 Q = 4000 m ³ /h and Ws = 3 m/s	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Condition 4 Q = 4000 m ³ /h and Ws = 4 m/s	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Condition 5 Q = 4000 m ³ /h and Ws = 10 m/s	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

The dilution results presented in Tables B.9 to B.12 for Condition 4 (a discharge rate of 4000 m³/h and a wind speed of 4m/s) are shown graphically in Figure 4.10 (45 deg TN), Figure 4.11 (255 deg TN) and Figure 4.12 (345 deg TN).

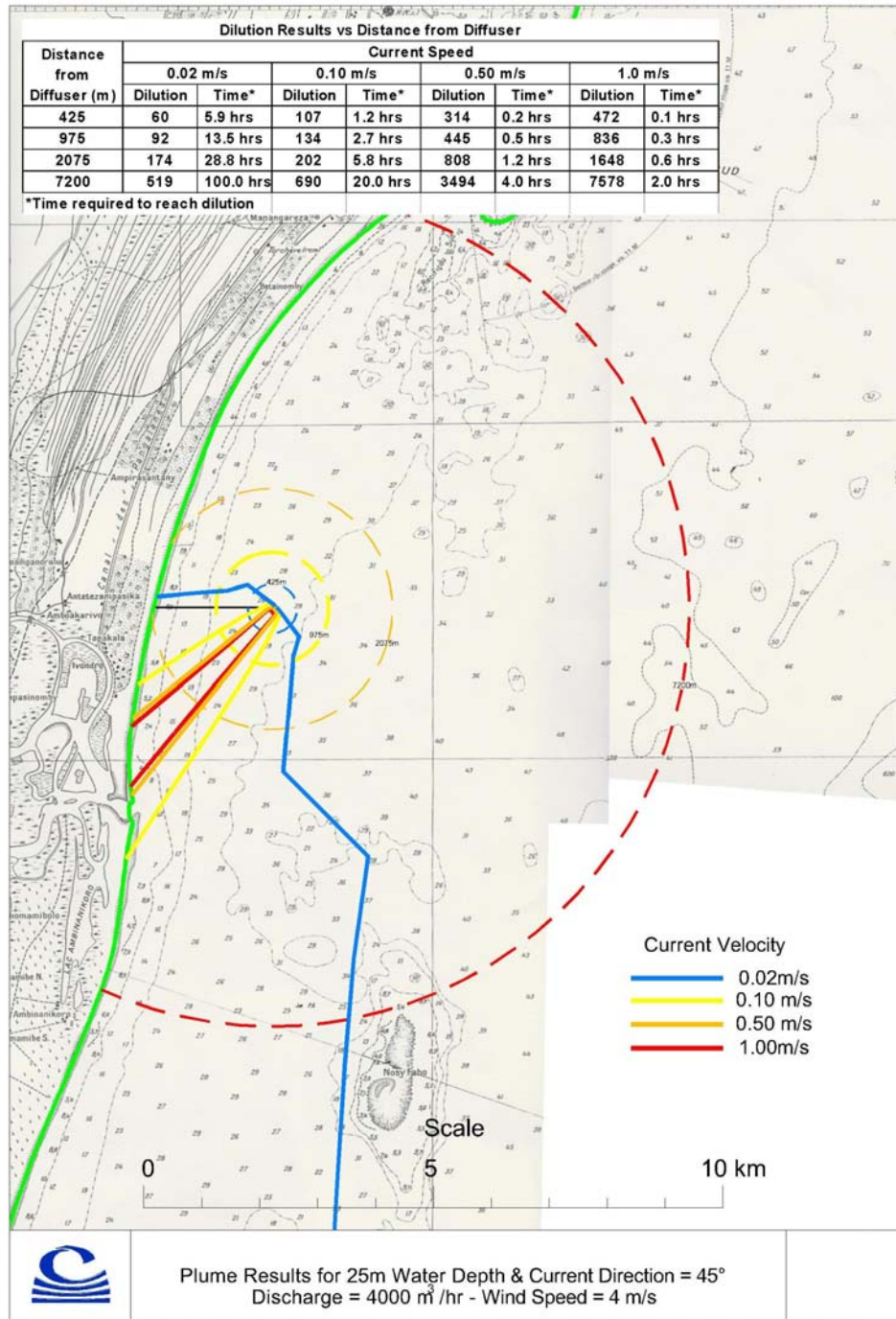


Figure 4.10: PRDW Plume analysis results for the 25 m water depth at a discharge rate of 4000 m³/hr, current direct 45° and wind speed 4m/s scenario.

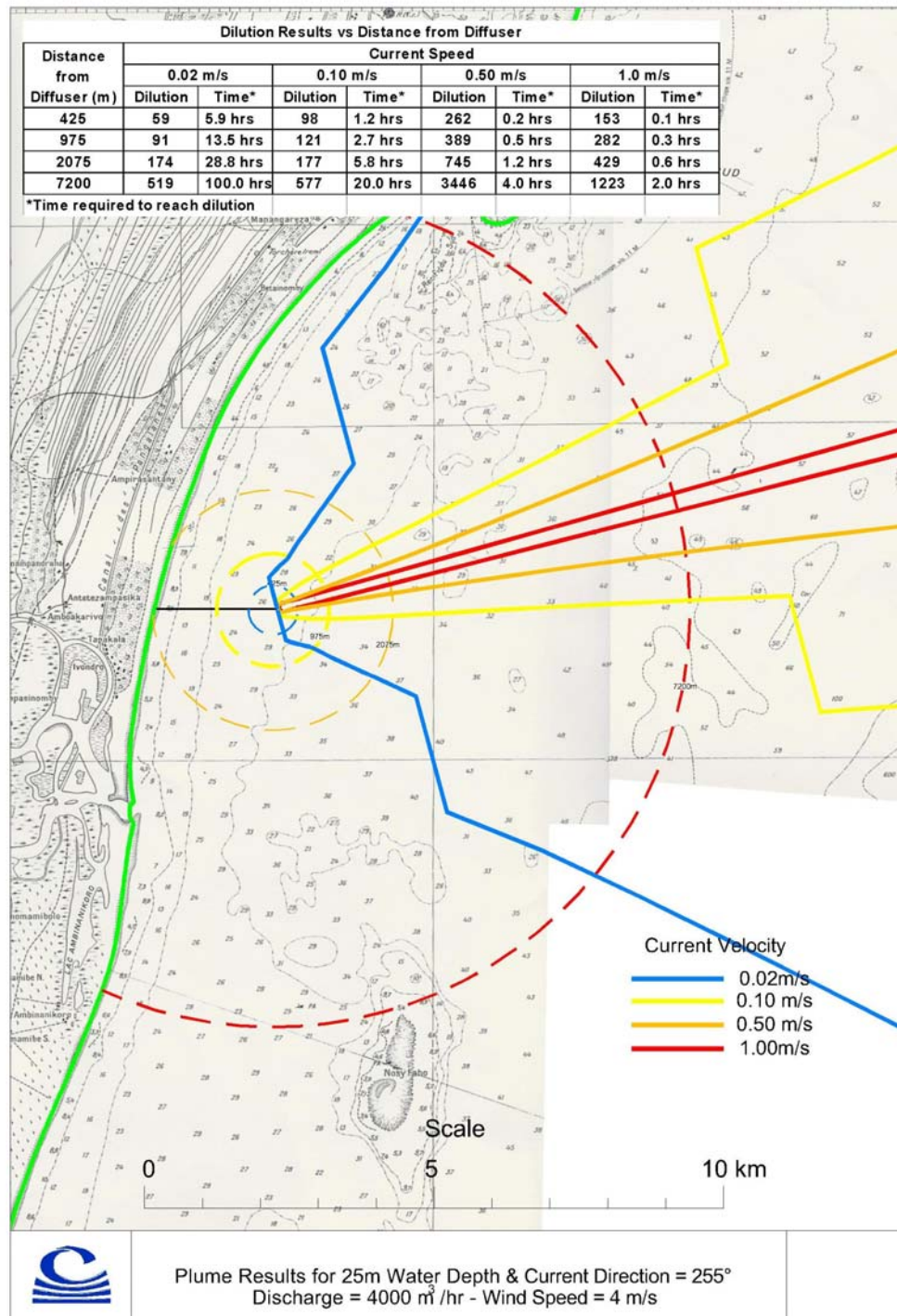


Figure 4.11: PRDW Plume analysis results for the 25 m water depth at a discharge rate of 4000 m³/hr, current direct 255° and wind speed 4m/s scenario.

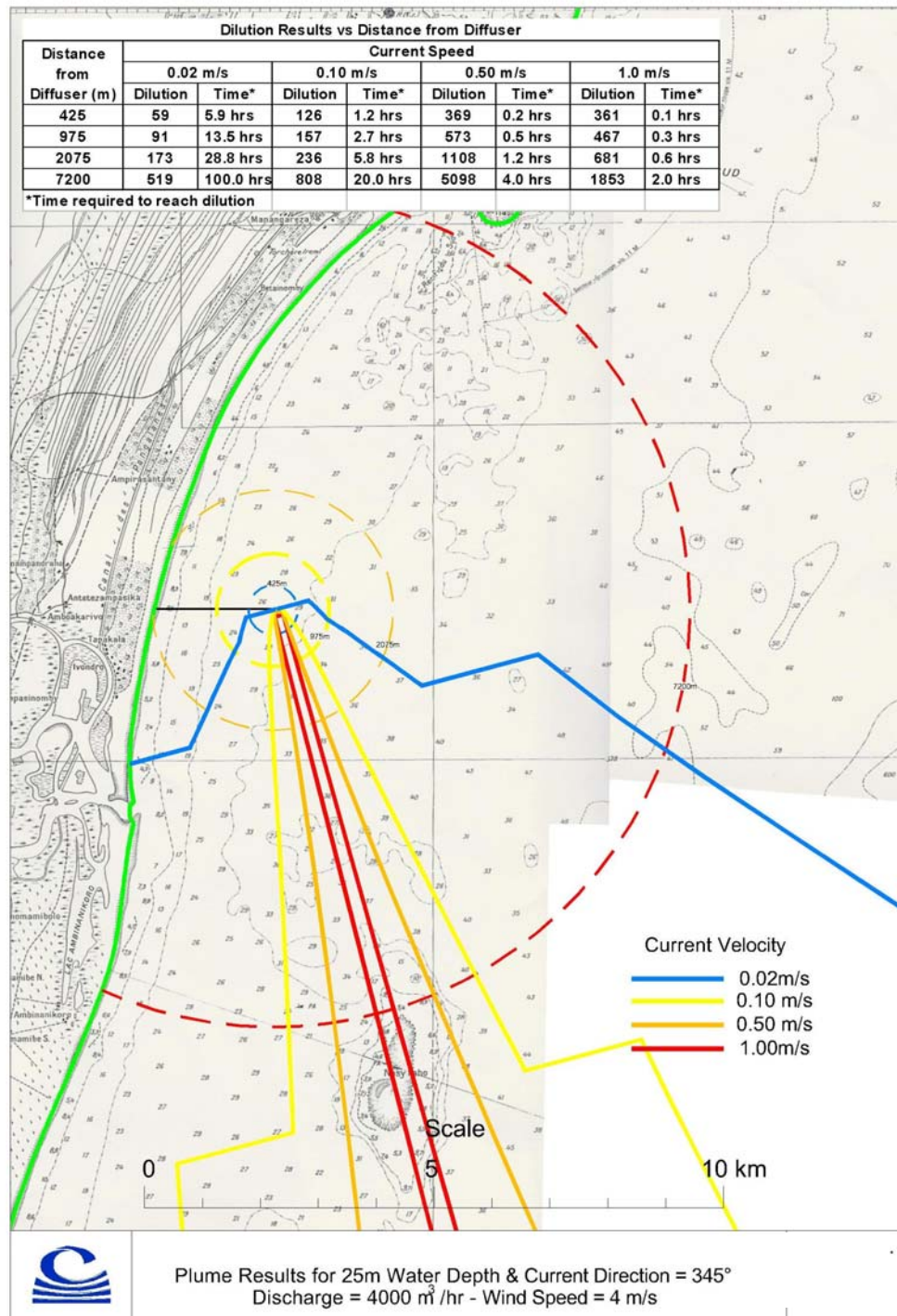


Figure 4.12: PRDW Plume analysis results for the 25 m water depth at a discharge rate of 4000 m³/hr, current direct 345° and wind speed 4m/s scenario.

4.7 SUMMARY

From the results presented the following can be concluded:

A diffuser located at 10 m water depth does not satisfy the water quality criterion for the conditions modeled. A minimum wind speed of 3 m/s would be required in order for the criterion to be satisfied. Based on the wind statistics provided this wind speed corresponds to a non-exceedence probability of 10%, or 37 days per year. From these results the 10 m water depth does not appear to be viable.

A diffuser located at 20 m water depth satisfies the water quality criterion for all conditions modeled.

A diffuser located at 25 m water depth satisfies the water quality criterion for all conditions modeled.

From an engineering design point of view a diffuser line located at a water depth of 20 m is preferred at this stage. This is subject to change once more detailed 3D hydrodynamic modelling is carried out using comprehensive field measurements as input. **The results to follow will be presented at a water depth of 20 m.**

4.7.1 EFFECT OF DISCHARGE RATES

From the results presented in Tables B.1 to B.12 (Appendix 4), it is concluded that by reducing the discharge rate from 4000 m³/s to 2000 m³/s would increase the overall dilution.

The results to follow will be presented for the most conservative discharge rate modeled, i.e. 4000 m³/s.

4.8 EFFECT OF CURRENT DIRECTION

As indicated in Section 5.1.4 the current direction can not be modeled correctly with the CORMIX model. By changing the ambient current direction from diffuser perpendicular to diffuser parallel a reduction in dilution is observed. This statement is supported by the results presented in Table B.1 through to B.12.

It is for this reason that the dilution results for an ambient current condition from 255° TN (most conservative case) will be presented in the sections to follow.

4.8.1 EFFECT OF CURRENT SPEED

Figure 4.14 presents the horizontal (a) and vertical mixing (b) (dilution) results as a function of centreline chainage (measured from the centre point of the diffuser) for:

- A water depth of 20 m

- A discharge rate of 4000 m³/s
- No wind
- Varying current speeds (0.02 m/s, 0.1 m/s, 0.5 m/s, 1 m/s)
- A current direction of 255° TN

From this figure it can be concluded that the dilution results improve as the current speed increases.

Figure 4.13b illustrates that for a current of 0.02 m/s the buoyant effluent would rise rapidly to the surface and begin dispersing within a narrow vertical band. For conditions with larger current speeds, the effluent reaches a terminal level at water depths closer to the sea bed. For these larger current speed conditions the trend is for the farfield dispersion process to begin at larger distances away from the diffuser. These conditions result in larger vertical mixing with larger dilution occurring downstream within wider bands.

Figure 4.14 is a contour plot of average dilution versus distance away from the diffuser centre point for a condition with a current speed of 0.02 m/s. The figure consists of circular rings spaced at 1000 m intervals around the diffuser centre point. The dilution values at these intervals are provided along with the time required for the plume to travel such distances. Figures 4.15 and Figure 4.16 show the same information for current speeds of 0.1 m/s and 0.5 m/s, respectively.

SPM (1984) states that wind forcing can generate surface currents up to 2 % of the wind speed magnitude. If this is adopted here (as a first order estimation) then a surface current speed of 0.02 m/s would theoretically be generated for a wind speed equal to 1 m/s. From the wind statistics provided the non-exceedance probability of a wind speed of 1 m/s can be estimated as 1.6 % or 5.9 days per year.

A current speed of 0.02 m/s is considered to be the most conservative current condition. The effect that wind speed has on the dilution results (as explained in the next section) will be investigated in terms of this current speed.

4.8.2 EFFECT OF WIND SPEED

Figure 4.17 presents the horizontal (a) and vertical (b) mixing (dilution) results as a function of centreline chainage (measured from the centre point of the diffuser at 20 m water depth) for:

- A discharge rate of 4000 m³/s
- Varying wind speeds (no wind, 1 m/s, 3 m/s and 4 m/s)
- A current speed of 0.02 m/s
- A current direction of 255° TN

Figure 4.17a indicates that the dilution results improve as the wind speed increases. This improved dilution is attributed to the vertical mixing induced by the larger wind speeds.

Figure 4.17b illustrates that for a wind speed of 1 m/s and a current speed of 0.02 m/s the buoyant effluent plume would rise rapidly to the surface and begin dispersing within a narrow band. The farfield dilution process would however begin further downstream (away from the diffuser) for increasing wind speeds. As the wind speed increases, the vertical plume width increases, which indicates greater dilution.

4.9 INTERPRETATION OF DILUTION RESULTS

The following comments can be made about the results presented:

- Reducing the discharge rate improves the overall dilution results in most cases.
- Ambient currents at right angles to the diffuser line result in improved farfield dilution compared to currents orientated parallel to the diffuser line.
- Increased current speeds results in increased dilution
- Inclusion of the wind parameter in the CORMIX model induces vertical mixing and improves dilution results, especially in the case for modeled currents below 0.1 m/s.

The results indicate that for a conservative condition with a current speed of 0.02 m/s and a wind speed of 0 m/s, the water quality criterion required is not reached before the effluent plume makes contact with the coastline for a marine outfall diffuser positioned in 10 m water depth.

A marine outfall extending to a total average distance of 975 m from the shoreline should satisfy the water quality criteria adopted for the site under all environmental conditions. If more refined hydrodynamic modelling is carried out using detailed wind and current measurements this recommendation may be refined.

Based on the environmental data made available for this study and the results presented, a marine outfall extending to a water depth of 20 m is recommended.

4.10 SETTLING OF SOLIDS

4.10.1 INTRODUCTION

Solids consisting mostly of hematite and gypsum occur in the effluent at a concentration of 50 mg/l as it leaves the diffuser port. The impact of this material settling to the bottom needs to be assessed as part of the marine study. It is therefore important to estimate the spatial distribution of settlement and associated thickness of the deposition layers surrounding the outfall.

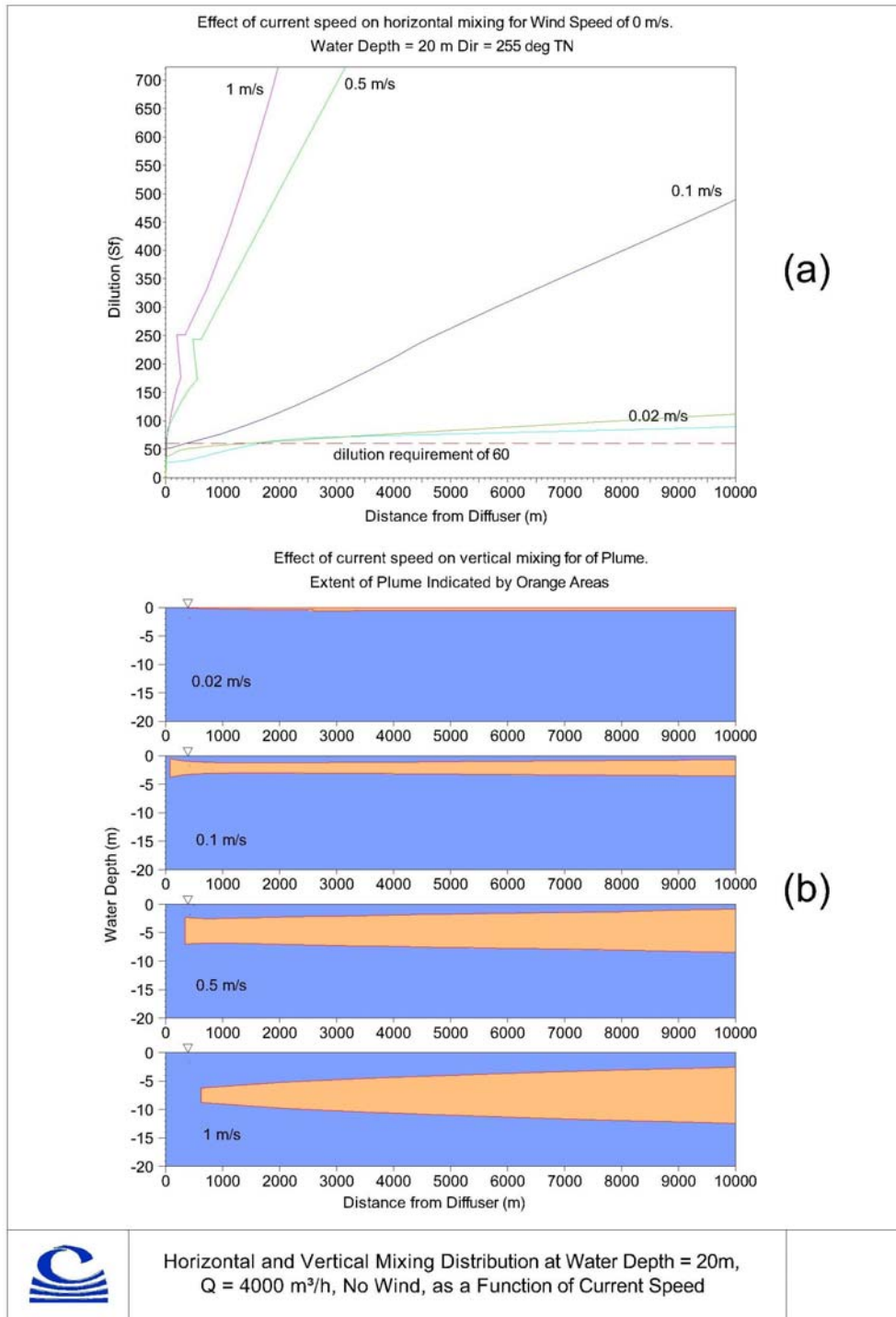


Figure 4.13: PRDW's results of the settling model with a water depth of 20, flow rate of 4000 m³/h and no wind.

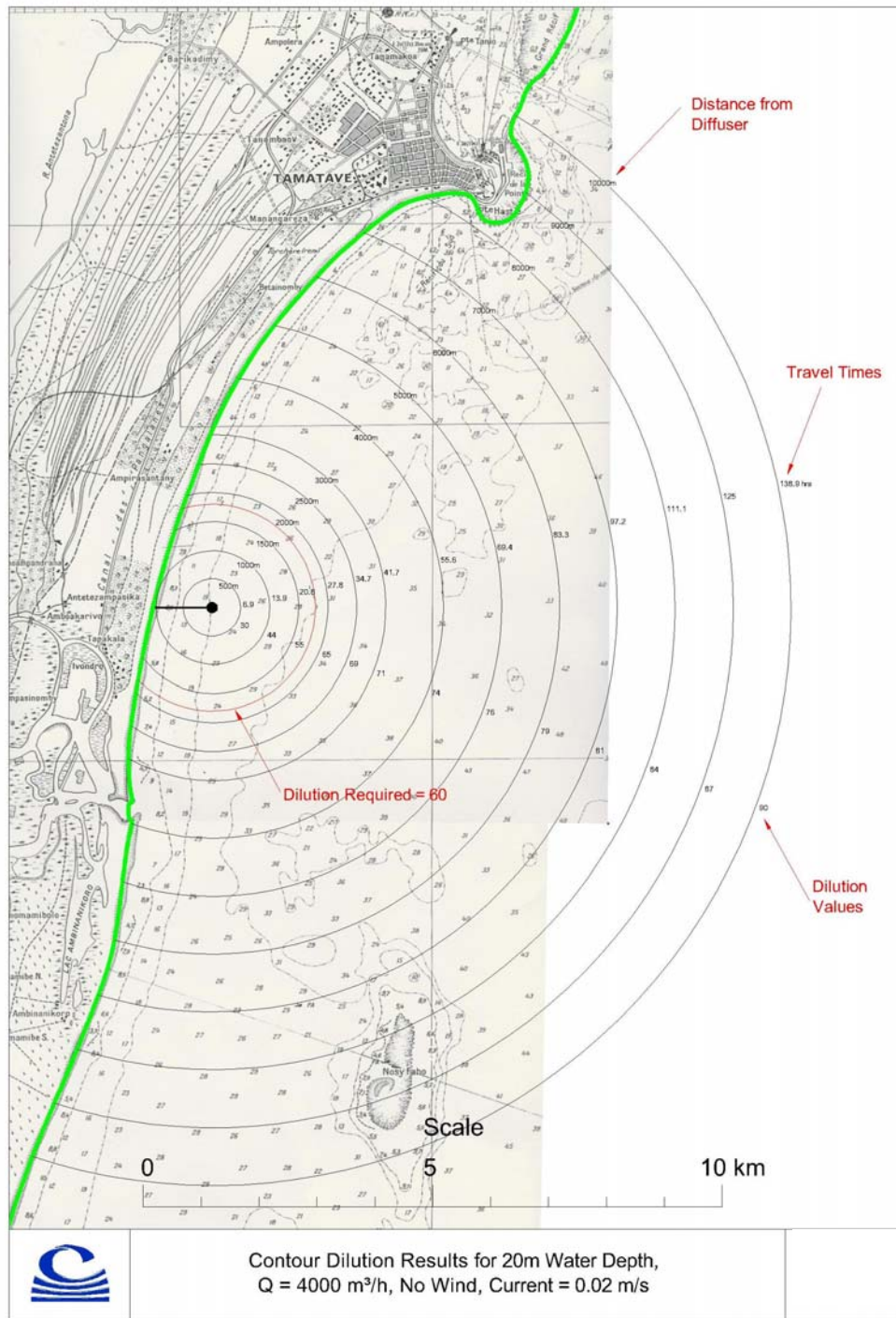


Figure 4.14: PRDW's contour dilution results with a water depth of 20, flow rate of $4000 \text{ m}^3/\text{h}$, no wind and a current speed of 0.02 m/s scenario.

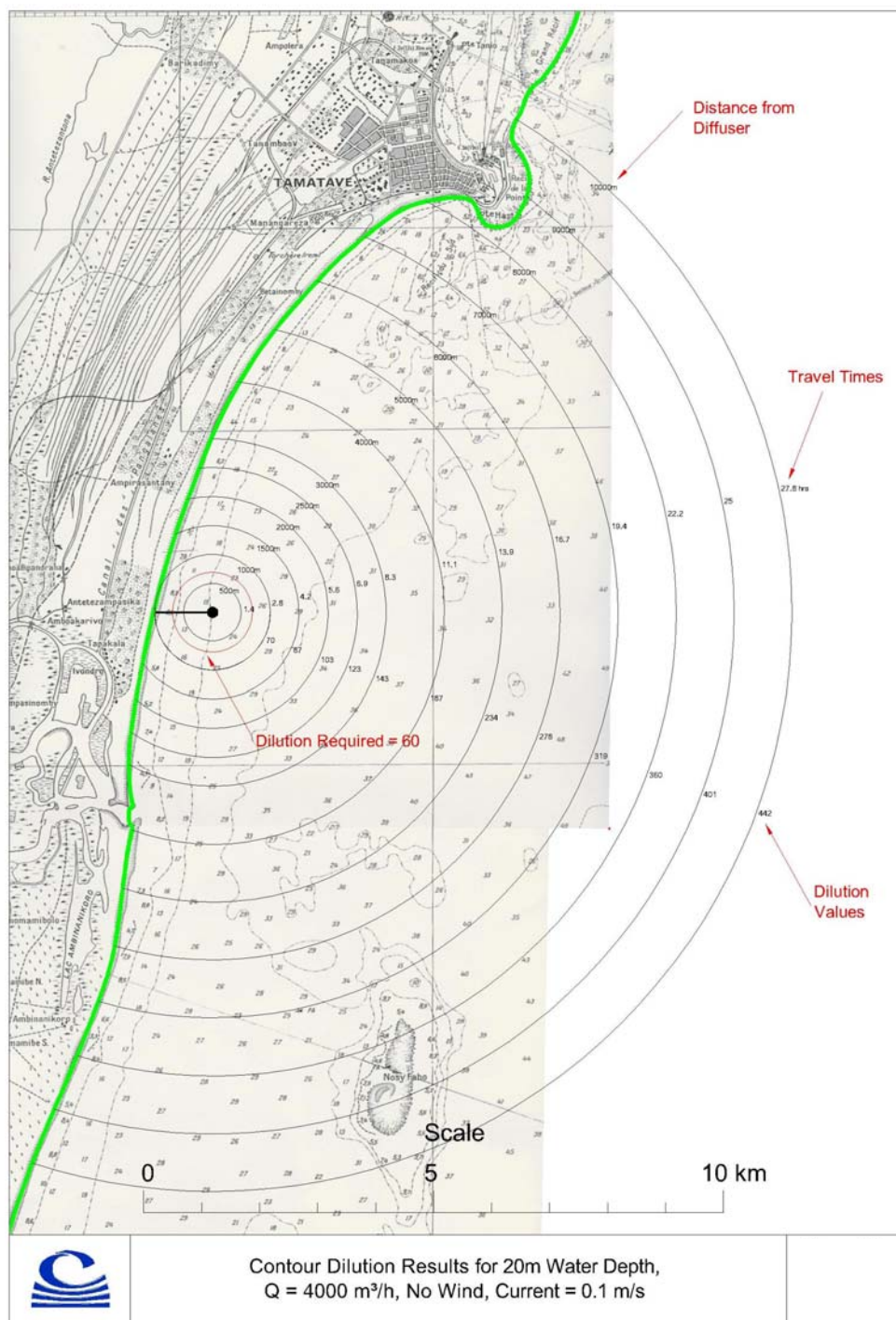


Figure 4.15: PRDW's contour dilution results with a water depth of 20, flow rate of 4000 m³/h, no wind and a current speed of 0.1 m/s scenario.

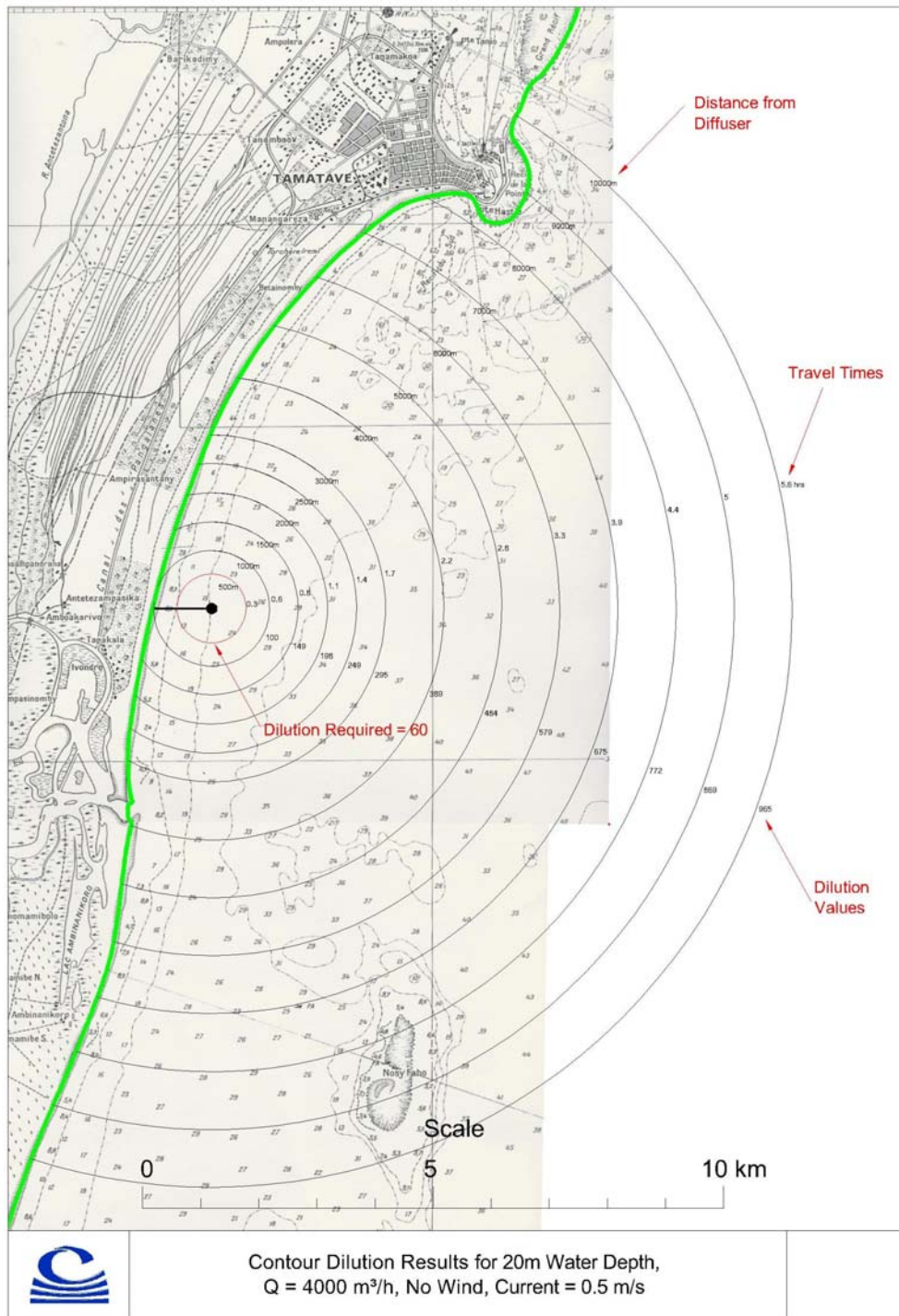


Figure 4.16: PRDW's contour dilution results with a water depth of 20, flow rate of $4000 \text{ m}^3/\text{h}$, no wind and a current speed of 0.5 m/s scenario.

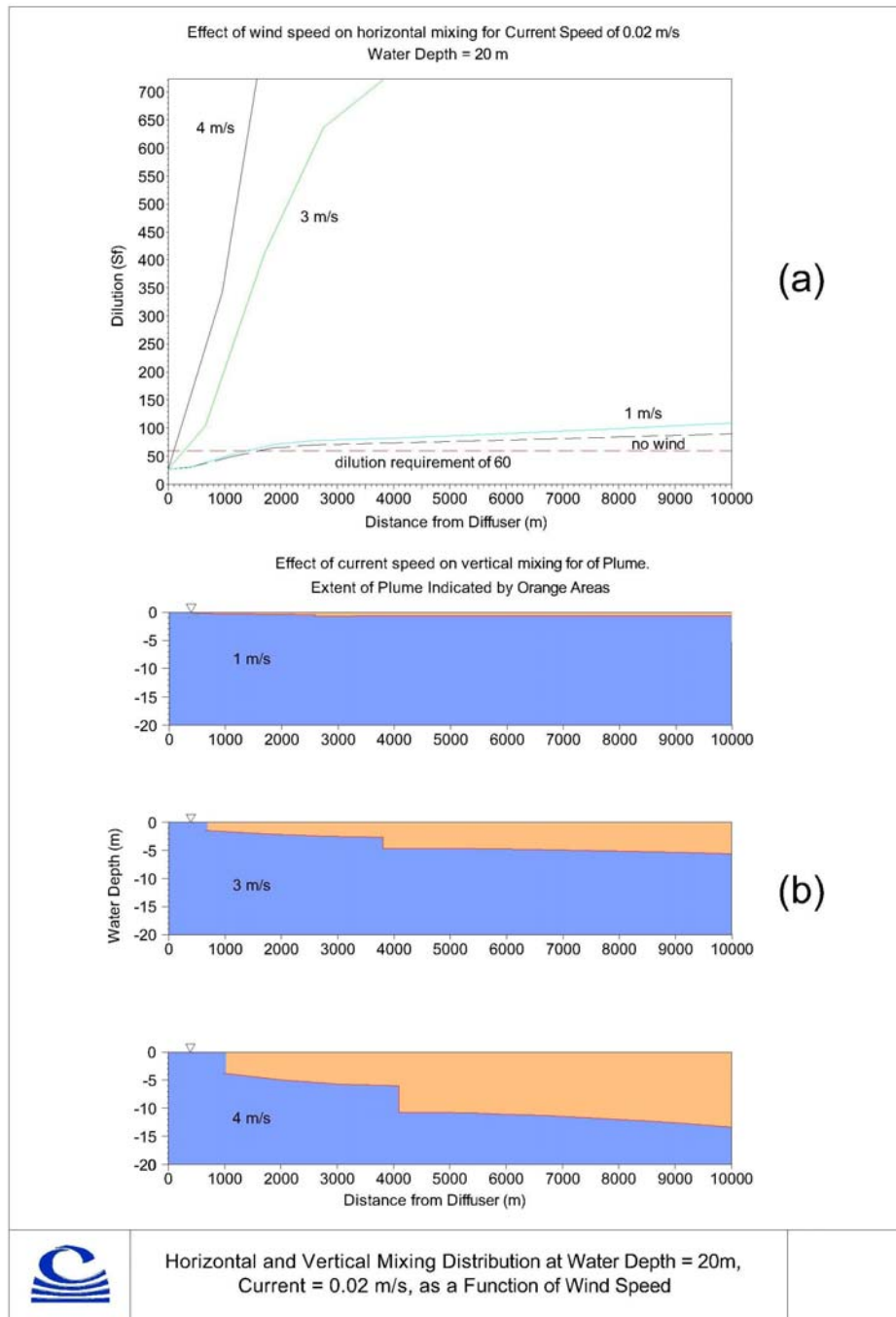


Figure 4.17: PRDW's results of the settling model with a water depth of 20, with a current speed of 0.02 m/s

4.10.2 MATERIAL DESCRIPTION

Information on the solid content was supplied by Dynatec, including the physical characteristics, composition, density and settling velocity.

Physical Characteristics

Solids SG (true density): 3.49

Particle Size:

Grain Size (um)	Percentage Passing (%)
250	99.90
150	99.80
90	98.90
63	98.60
45	96.70
37	95.70
22	90.00
3.6	50.00
1.1	10.00

The material consists of mainly spherical shaped reddish-brown particles when viewed through a microscope.

Composition

The material is a mix of hematite and gypsum, with lesser amounts of hydronium alunite, metal hydroxides, silica and unleached chromite.

Typical composition

Component	% By Weight
Fe	35.80
Ca	7.51
S	7.20
Si	2.87
Al	2.27
Cr	1.39
Mn	0.54
Mg	0.35
Ni	0.06
Co	0.01

Component Specific Gravities

Component	Specific Gravity
Gypsum	2.3 to 2.37
Silica (Quartz)	2.65
Hematite	5.26
Al(OH) ₃	2.42
Mg(OH) ₂	2.26
Mn(OH) ₂	2.58

Solids SG (true density): 3.49

4.11 SETTLING CHARACTERISTICS

Based on the particle size distribution and ranges in component densities, a range of different settling rates can be expected for fine and coarse particles. Appendix 4 provides the settling test report provided by Dynatec. It concludes that the material settles out in two main fractions, bulk solids and fines. The rate of settlement for fines is given as 0.18 m/hour (0.05 mm/s) while the bulk solids settle at much higher rates of up to 2 m/hour (0.56 mm/s) depending on the concentration of the solids.

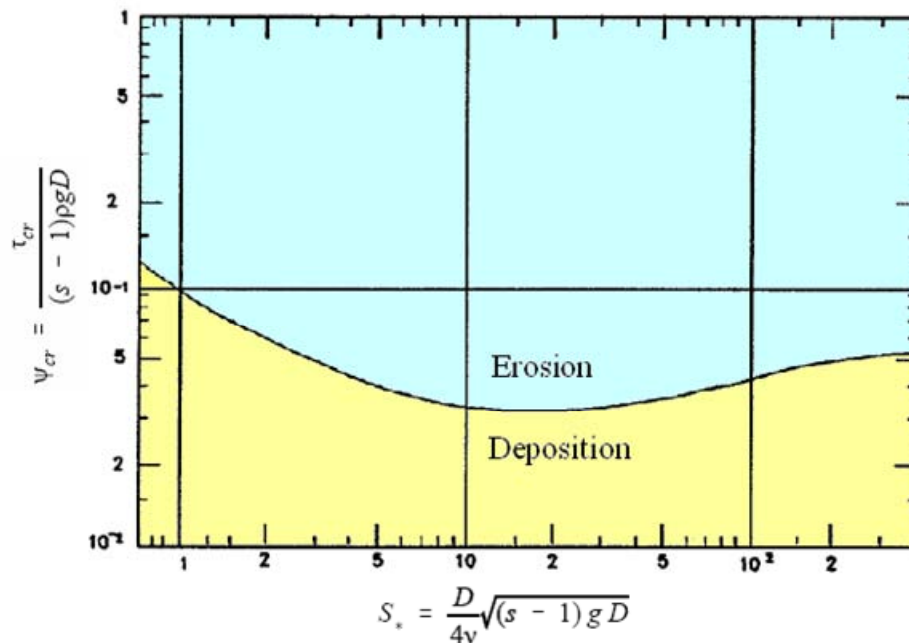
4.11.1 CRITICAL SHEAR STRESS

The well-known Shields diagram describes the flow induced shear stress for incipient motion of granular materials. CEM (2002) provides a modified Shields diagram that was used to estimate the shear stress at which deposited fines will start to be transported by flow. It should be noted that few experiments have been conducted with very fine grain sizes and the Shields diagram for the low part of the curve is therefore not that reliable.

The parameters used in the modified Shields diagram (CEM, 2002) are:

$$S_* = \frac{D}{4\nu} \sqrt{(s-1)gD} \quad \text{and} \quad \Psi_{cr} = \frac{\tau_{cr}}{(s-1)\rho g D}$$

where: D = grain diameter (m)
s = ρ_s / ρ
 ρ_s = density of sediment (kg/m³)
 ρ = density of water (=1025 kg/m³)
 ν = kinematic viscosity of water (=10⁻⁶ m²/s)
 τ_{cr} = critical shear stress for initiation of motion (Pa)



Modified Shields diagram for initiation of motion

For a grain size of 0.0036 mm and density of 3500 kg/m³, $S_* = 0.0083$. This value is lower than the range shown in the modified Shields diagram. CEM (2002) provides the following estimate for $S_* < 0.8$: $\Psi_{cr} = 0.1 S_*^{(-2/7)}$, which provides an estimate of Ψ_{cr} of 0.393 from which τ_{cr} can be calculated as **0.12 Pa**.

CEM (2002) states that cohesion may become important for such fine grained sediments but that this relationship would be a reasonable approximation if the sediment does not contain too much organic material and/or clay. Information on the cohesiveness of the fines was requested from Dynatec who produced a report on the rheology of the material as presented in Appendix 4. It is not clear how yield strengths of slurries determined with a rotoviscometer relates to the shear stress required for incipient motion of settled fines. A general interpretation of the results by Dynatec engineers was that the material can be expected to have some cohesive properties. For a final analysis of sediment transport due to flow induced shear hydraulic tests of incipient motion will be required.

4.11.2 IMPACT

The implication of the material settling on the bottom for various organisms has not been researched in detail, however, CES has indicated that impacts can be expected to be significant for depositional thicknesses in excess of 15 mm over the lifetime of the structure. This value will be highlighted in results to indicate areas that will potentially experience significant impacts due to settlement of solids.

4.11.3 INTERPRETATION OF MATERIAL CHARACTERISTICS AND SETTLING PROCESS

At a concentration of 50 mg/l and a discharge of 4000 m³/hour a total of 4.8 t of solids are discharged per day. For a production life of 27 years the total mass of solids discharged will be 47,304 t. With a density of 3.5 t/m³ and a depositional void ratio of 5 (typical for silt) the total volume of solids that will settle to the sea bed is 67,577 m³. If the discharge plume moves away from the diffuser at a constant speed s , in a constant water depth of d , the maximum distance, D , from the diffuser that solids will be deposited is given by:

$$D = s \cdot d / 0.00005$$

The time, t (hours), required to settle through a depth of d is: $t = d / 0.18$. For a water depth of 20 m this time is 111 hours (4.6 days) and the areas over which material can possibly settle out are estimated in Table 4.7.

Table 4.7: Maximum distance from diffuser that fines can be deposited.

Average Current Speed (over 4.6 days) Away from Diffuser (m/s)	Maximum Distance From Diffuser Where Material can be Deposited (km)
0.01	4
0.02	8
0.03	12
0.04	16

While current speeds of up to 0.4 m/s have been measured (Oceanide, 2005) these would relate to relatively short periods. Without the actual time series data of the recordings there is no real basis for estimating average current speeds over a 4.6 day duration. It would for instance not be possible to say that an average current speed of 0.04 m/s will never occur. The maximum range of influence in terms of deposition of solids might well be as much as 16 km from the diffuser. However, as the solids settle over larger areas the depositional thickness becomes less. As a first estimate of the depositional thickness it is assumed that the material is uniformly distributed around the diffuser up to the furthest point of influence. Table 4.8 gives estimates of this thickness for various radial distances.

Table 4.8: Average Theoretical Thickness of Deposition

Radial Distance From Diffuser (km)	Area (km ²)	Thickness (mm)	Average Current Speed (m/s)
1.0	3.14	21.5	0.0025
1.5	7.07	9.6	0.0038
2.0	12.57	5.4	0.0050
2.5	19.63	3.4	0.0063
3.0	28.27	2.4	0.0075

If material is deposited uniformly over a radial distance of 1.2 km from the diffuser the average depositional thickness will be just less than 15 mm. This provides a first estimate of the range over which a significant impact from the diffuser can be expected due to settling of solids.

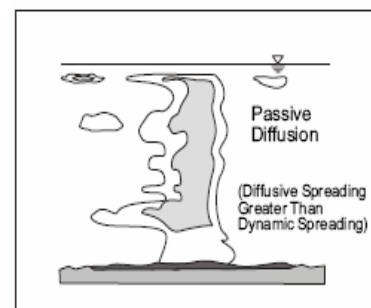
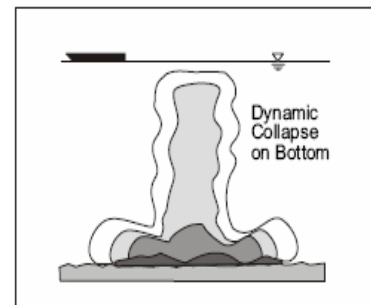
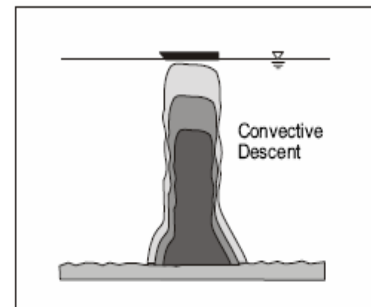
4.12 STFATE MODELLING

4.12.1 DESCRIPTION OF MODEL AND

APPLICATION TO AMBATOVY

STFATE was developed to model disposal plume behaviour around a dredge disposal site. STFATE models the behaviour of the plume as a dense liquid applying conservation of mass, momentum, buoyancy, and particle fall velocities. The behaviour of the plume is separated in three phases: convective descent, dynamic collapse and passive diffusion. For application to the settlement of fines for the Ambatovy effluent, only the process of passive diffusion is applicable. During convective descent a dredge plume settles under the influence of gravity and dynamic collapse occurs when the descending plume impacts the bottom and diffuses horizontally due to its own momentum. For the rising buoyant plume from the diffuser these two processes are not applicable and only the passive diffusion results from STFATE are therefore considered for estimating deposition around the proposed Ambatovy outfall.

Passive diffusion begins when the plume's behaviour is driven more by the ambient oceanographic conditions (currents and turbulence) than by the dynamics of the plume body and is therefore similar to farfield dilution. For the low concentration and low settling velocity of the fines contained in the Ambatovy effluent, STFATE reports that the process of convective descent will not occur.



Physical processes modeled by STFATE (After Battelle, 2004)

For the Ambatovy case STFATE models the dynamic collapse of the plume during which approximately 5 percent of the fines are deposited. The remaining 95 percent remains suspended in a cloud similar to that which can be expected to result from diffuser discharge depending on prevailing wind and current conditions. Then, using ambient currents, it tracks the movement of the remaining suspended particles during the passive diffusion phase, modelling their slow fall to the seafloor due to gravity, the counterbalancing effect of turbulence which tends to keep them suspended, and the horizontal diffusion of the plume.

The basic assumption used for simulating a continuous diffuser discharge with STFATE was that the continuous discharge could be simulated with a series of dredge dumps.

4.12.2 MODEL PARAMETERS AND APPROXIMATIONS

Due to the very slow settling velocity, a number of model values had to be set outside typical ranges used for modelling dredge material.

Deposition results were the same for both hopper and barge disposal. This indicates that deposition is mainly determined by long term transport and diffusion and that a choice between barge or hopper disposal is not significant for the model results.

The maximum number of grid cells was used for all runs (45 by 45).

The maximum duration that could be simulated without errors was 800,000 seconds (7 days).

The fall velocity was kept constant at 0.00016 ft/s (0.05 mm/s).

Spreading and dilution due to nearfield effects of the diffuser was not modelled. Some spreading due to dredge release are included in STFATE modelling, but since this process does not play a significant role in deposition the accuracy of initial dilution and spreading is not considered important.

To ensure that the required dilution of 25 is obtained in the near field the concentration of solids will be approximately 2 mg/l after nearfield dilution of the buoyant plume. However, the total discharge of solids from the diffuser is 50 mg/l which will settle irrespective of the amount of dilution. For low solid concentration values the density of the effluent is not significantly affected by the presence of the solids. For the present case, settling of solids is expected to take place as individual particles with the effluent remaining at the surface as a buoyant plume.

STFATE could not be used to model volumetric concentrations of solids lower than 0.0008. For a 50 mg/l concentration the volumetric concentration is 0.000014 (570 times less than 0.0008). The effect of concentration on settlement is shown in Figure 4.18 where the depositional thicknesses of two different concentrations are compared. The condition that was modelled is that of a current speed of 0.1 m/s (in a north westerly direction) and results have been scaled up to so that the total volume of deposition is

67,577 m³ (total volume that will be deposited over 27 years). Although there is reasonable agreement between the contours from the two cases, the higher concentration shows deposition closer to the diffuser. Results with the concentration of 0.0008 are therefore likely to be conservative in terms of deposition thickness close to the diffuser (compared to the actual concentration of 0.000014). In terms of the maximum distance away from the diffuser that material might settle, results will not be conservative. However, at distances of more than 2 km away from the diffuser the layer thickness of deposited material is expected to be less than 5 mm thick after 27 years. For a thickness of less than 15 mm the impact of the material is not considered significant.

Characteristic values of effluent:

Concentration of solids:	50 mg/l = 0.05 kg/m ³
Solids density:	3500 kg/ m ³
Depositional void ratio:	5 (assumed)
Density of deposited solids:	3500/5 = 700 kg/ m ³
Volumetric concentration of solids:	0.05/3500 = 0.000014 m ³ / m ³
Mass of solids t discharged over 27 years:	27 x 365 x 24 x 200 = 47,304,000 kg
Total volume of solids over lifetime:	47,304,000/3500 = 13,515 m ³

Total volume of solids deposited over the lifetime of structure: 47,304,000/700
= 67,577 m³

Values modelled in STFATE:

Total volume of layer:	26670 yd ³ = 20391 m ³
Volumetric concentration:	0.0008
Total volume of solids:	576 ft ³ = 16.31 m ³
Total mass of solids:	16.31 x 3500 = 57,085 kg
Depositional void ratio:	5
Total volume of deposited solids:	81.5 m ³
Cohesionless material was specified	

Critical shear stress for deposition: 0.007 lbs/ft² = 0.33 Pa (typical value for silt and clay)

Factor to convert model run to depositional thickness for 27 years: 47,304,000/57,085 = 829

For a flow rate of 4000 m³ per hour and concentration of 0.05 kg/ m³, the rate of solid discharge is 400 kg/hour. The time required to discharge 57 085 kg solids is: 57 085/400 = 142.7 hours (6 days)

4.12.3 MODEL RESULTS

Similar to the approach used in Figure 4.18, all model results were scaled up to the total volume of material that would be discharged over 27 years at an effluent discharge rate of 4000 m³ and a solids concentration of 50 mg/l. This concentration is considered a maximum for the project with average values closer to 20 mg/l. Model results can simply be scaled according to concentration values and the 20 mg/l contours will therefore be 60 percent lower than the 50 mg/l contours.

Figure 4.19 shows the deposition contours for a current speed of 0.05 m/s, which is close to the average current speed for winter in a depth of 19 m (0.04 m/s). A current from due north was selected for the plot but of course a distribution of directions similar to that shown in the current rose is to be expected. The maximum contour shown is 13 mm and is approximated by a circle with radius of 200 m. It would therefore appear that average current conditions will not produce significant areas with depositional contours of more than 15 mm over the lifetime of the structure.

Figure 4.20 shows the deposition contours for a current speed of 0.25 m/s, which is close to the maximum current that can be expected in summer in a depth of 19 m (0.26 m/s). The current direction was chosen to illustrate potential impacts on Recif du Sud. This current will not occur often and plotting depositional contours as if this is an average condition provides a very conservative estimate of the maximum distance that solids will settle away from the diffuser.

Figure 4.21 shows the deposition contours for a condition with zero current. This represents the critical condition for maximum deposition thickness. A thickness of 15 mm is reached within a radial distance of approximately 200 m from the diffuser.

4.12.4 TRANSPORT BY WAVE ACTION

Water motion on the sea bed due to wave action will tend to stir up fines and keep them in suspension. Any net current will cause transport of these suspended fines. Incipient motion will occur when the bottom shear stress exceeds the critical shear stress of 0.12 Pa. Bottom shear stress due to wave action was calculated according to CEM (2002) as indicated in Appendix 4. Bottom roughness can be well approximated by using the bottom grain size. For the conditions considered the flow regime was found to be smooth turbulent for bottom roughness values of 0.2 mm and less. Actual grain sizes over the area of interest are expected to fall within this range. An exact roughness value is not important in the smooth turbulent zone since shear stress is independent of bottom roughness for this flow regime. Table 4.9 shows results for a depth of 20 m. The percentage exceedance of wave height from Oceanide (2005) is included to show the significance of specific wave heights. Figure 4.22 shows a representation of deposition based on the effect of bottom currents.

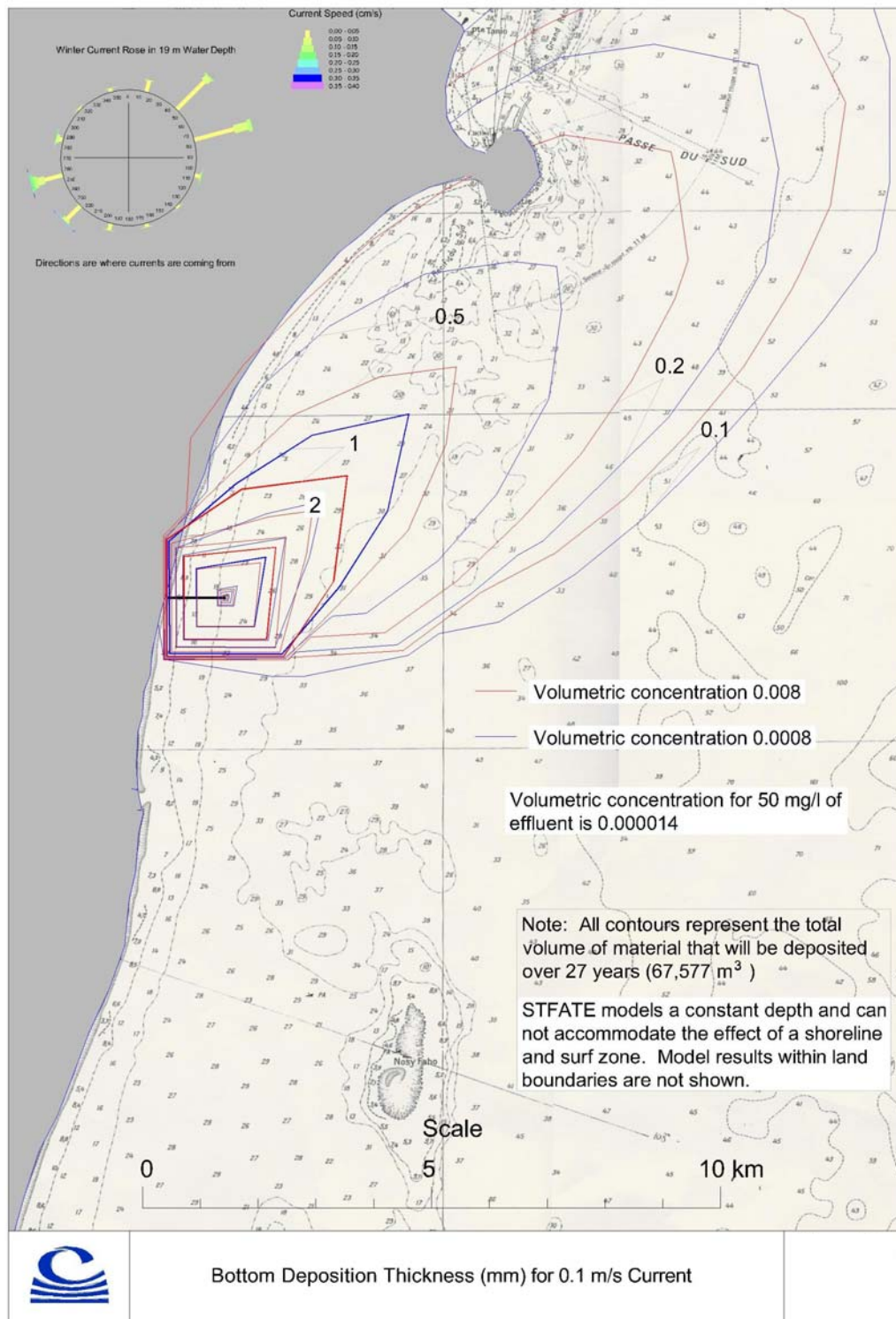


Figure 4.18: Representation of bottom deposition area over the 27 year period for a 0.1 m/s current speed.

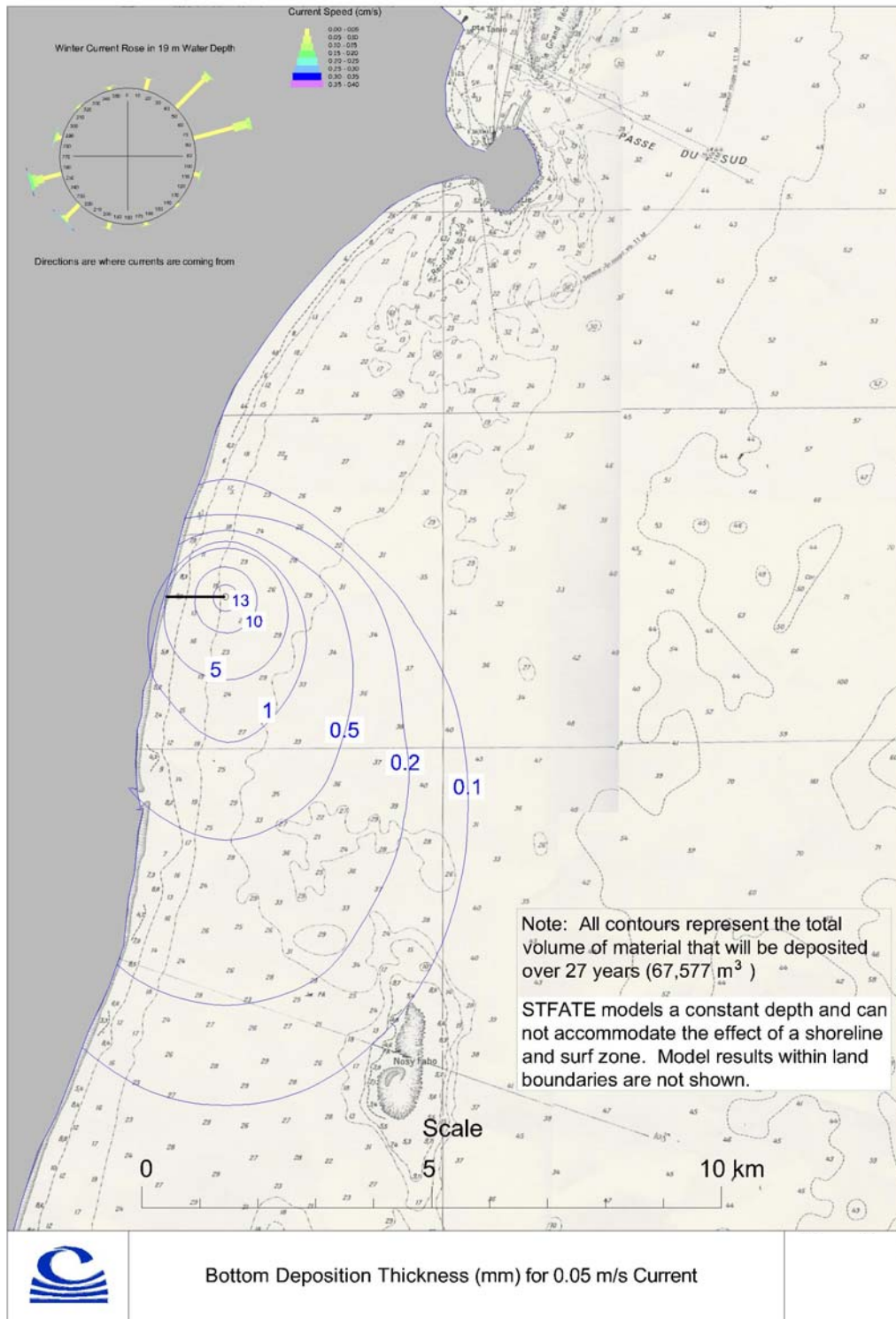


Figure 4.19: Representation of bottom deposition area over the 27 year period for a 0.05 m/s current speed.

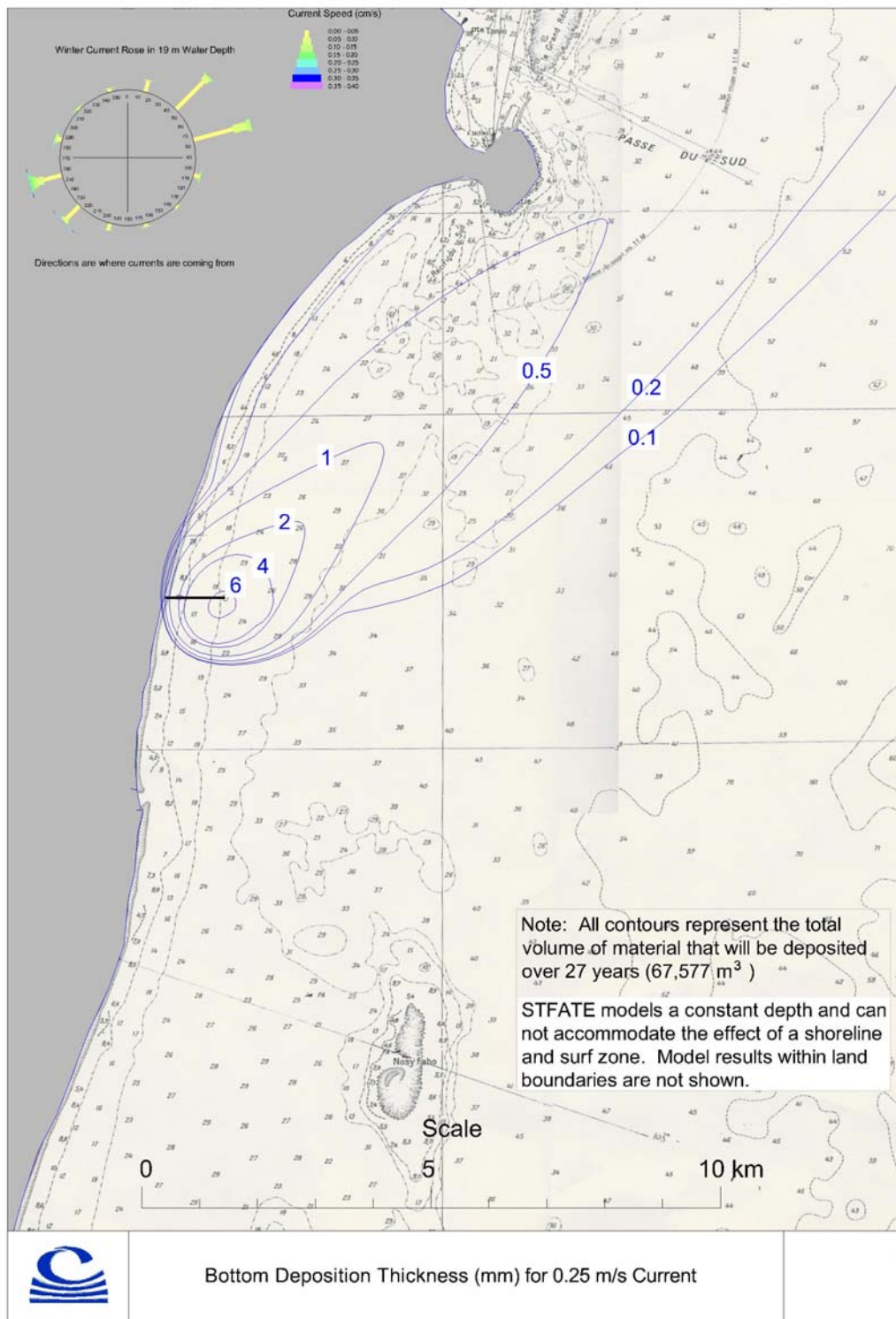


Figure 4.20: Representation of bottom deposition area over the 27 year period for a 0.25 m/s current speed.

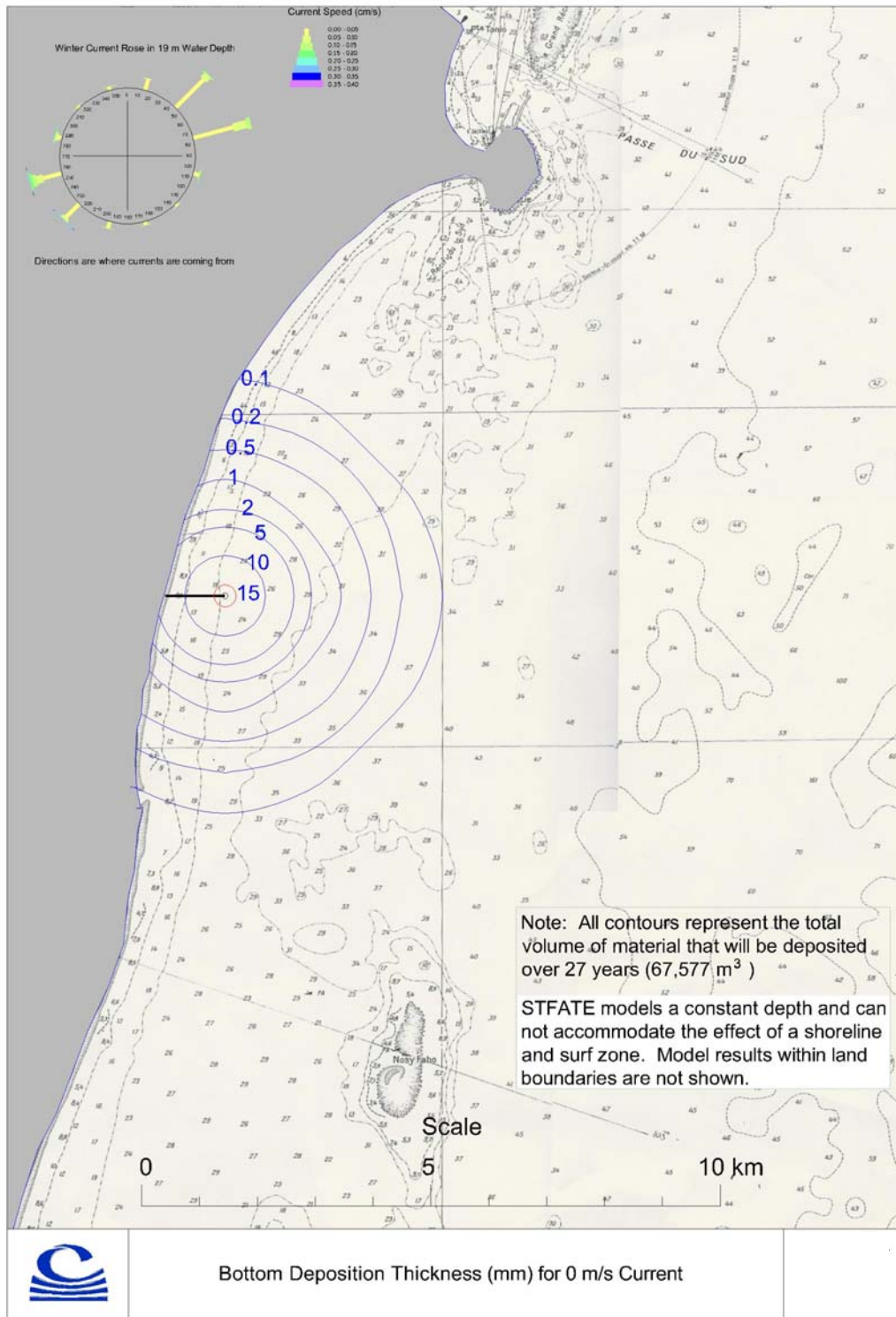


Figure 4.21: Representation of bottom deposition area over the 27 year period for zero current.

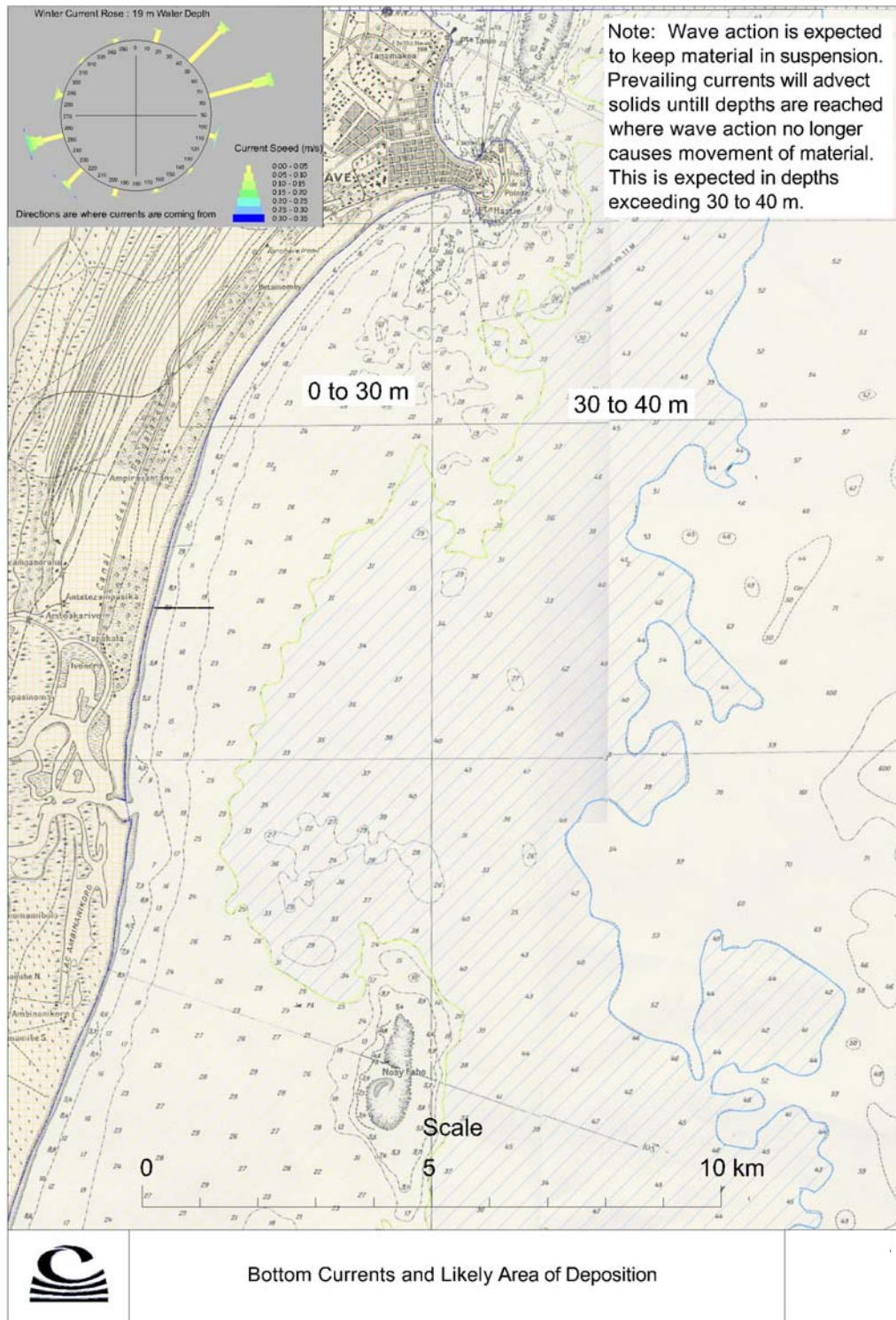


Figure 4.22: Representation of deposition based on the possible effect of bottom currents.

Table 4.9: Bottom shear stress due to wave action in 20 m water depth. Exceedence of wave heights from Oceanide (2005).

Significant Wave Height (m)	% Exceedence	Root Mean Square Wave Height (m)	Wave Period (s)	Maximum orbital displacement on bed (m)	Maximum orbital velocity on bed (m/s)	Shear velocity on bed (m/s)	Shear stress on bed (Pa)
1.25	83	0.88	8	0.23	0.18	0.013	0.17
1.50	70	1.06		0.27	0.21	0.015	0.22
1.75	56	1.24		0.32	0.25	0.016	0.28
2.00	40	1.41		0.36	0.29	0.018	0.34
1.25	83	0.88	10	0.36	0.23	0.015	0.22
1.50	70	1.06		0.43	0.27	0.017	0.30
1.75	56	1.24		0.50	0.32	0.019	0.38
2.00	40	1.41		0.57	0.36	0.021	0.46

These values are presented in Figure 4.22 together with results for 30 m and 40 m water depths. The limiting value of 0.12 Pa is also shown together with a typical value for the transition of silt to clay as suggested by STFATE (0.33 Pa). If the critical shear stress of 0.12 Pa is confirmed it will imply that deposited material will be suspended by wave action for most of the time in water depths of up to 40 m. Even at a value of 0.33 Pa it is unlikely that material will settle in depths of less than 30 m. These areas are highlighted in Figure 4.22

The transport of material subsequent to deposition will distribute material over a large area. Depending on prevailing current conditions material can be moved significant distances alongshore until an offshore movement deposits material in depths exceeding 30 m to 40 m (depending on the critical shear stress of material). These wave induced movements will flatten out deposits and is expected to result in significantly lower deposition thickness than that predicted by STFATE modelling.

It would be possible for material to settle in shallower areas sheltered from wave action, such as the lee of Nosy Faho or in the Tamatave Port area. However, by the time that material reaches these locations it will be of a very low concentration and layer thickness would not be expected to exceed a few millimetres after the cumulative discharge of 27 years.

4.13 INTERPRETATION OF RESULTS

Estimates of areas over which fines are expected to settle have been made based on approximate modelling with STFATE. Contours of deposition resulting from a cumulative discharge of 27 years include a number of assumptions and approximations. It also appears likely that wave action will prevent material from settling in depths of less

than 30 m and will continuously re-suspend material until it is transported to depths where wave action no longer causes suspension. To achieve accuracy in modelling these processes the following would be required:

- Sophisticated 3D hydrodynamic model capable of modelling flow from the diffuser up to radial distances of 10 km;
- Transformation of waves due to shoaling, refraction and diffraction to be included in the modelling;
- Using the full hydrodynamic model results include settling of fines from a buoyant plume during advection-dispersion processes; and
- Model bed erosion of soft and partly consolidated material including bed shear stresses due to waves.

A good approach to including these complex processes in modelling would be to use DHI's MIKE3 suite of models, including the MIKE MT mud transport module. In order to justify the cost of doing such sophisticated modelling, accurate boundary conditions are required. These should include:

- Time series data of current profiles covering the entire water column at a minimum of two locations for a period of one year.
- Concurrent wind, tide and wave measurements at hourly intervals.
- Additional properties of fines including:
- Spectrum of settling velocities for grading curve under representative conditions
- Potential of aggregation/flocculation
- Consolidation of settled material
- Critical shear stress for various levels of consolidation

In the light of these requirements it should be clear that results from the present study should be carefully interpreted. As a general indication of maximum build-up that can be expected close to the diffuser results are considered meaningful and on the conservative side. Aggregation and flocculation of material could potentially increase the settling velocity of material but this is not considered likely if the concentration of fines is limited to 50 mg/l. Additional testing of settling characteristics in sea water at representative concentrations should be undertaken to confirm this.

4.14 CONCLUSIONS AND RECOMMENDATIONS

4.14.1 MODELLING AND LIMITATIONS

Dilution modelling was done with CORMIX. This EPA approved model relies on a number of empirical relationships and can not model the cumulative build-up of effluent under very calm conditions. It models the coast as a straight line with a constant depth. Settlement of fines was modelled with STFATE. This EPA approved model was developed for dredge disposal. Similar to CORMIX it can not model the actual

bathymetry of the site. It does not include the effect of wave action or the influence of the surf zone. A number of approximations were required due to the low settling velocity of fines. Measurement of wave, current and wind were only available in a summarized format. Having access to the time series data would enable realistic estimates of average conditions over the period that fines are expected to settle to the bottom (approximately 5 days).

Re-suspension of settled sediment by wave action and transport to deeper water was evaluated using the methods of CEM (2002). This does not allow prediction of final deposition contours. The flow induced shear stress resulting in incipient motion of fines was not available which limited the estimation of wave conditions that would produce suspension in specific water depths.

4.14.2 RESULTS AND INTERPRETATION

Dilution results indicate that the diffuser should be located in a water depth of 20 m at a distance of 975 m from the shoreline to ensure that a dilution of 25 times is reached prior to the effluent reaching the shore and the reefs. A fairly high degree of confidence is attached to this result. Improved estimates would be possible if more detailed measurements over a one year period were available.

STFATE was used to model the deposition of fines in a constant depth of 20 m. It required a number of approximations and assumptions due to the very low settling velocity of the sediment. Results indicate that a critical depositional thickness of 15 mm over the lifetime of the outfall is likely to be limited to a radial distance of less than 200 m from the diffuser ports. Although prediction of depositional contours using the STFATE results is considered to have a low degree of confidence, results close to the diffuser are considered to be on the conservative side. Re-suspension of material is expected under higher wave conditions which will tend to spread deposited material out over a larger area.

4.14.3 RECOMMENDATIONS FOR FUTURE WORK

In terms of dilution modelling the main shortcoming is accurate, detailed data of waves, currents and wind covering a period of one year. Improved dilution modelling that includes the hydrodynamics of the coastline and potential of effluent build up should be undertaken once these measurements are available.

Modelling the final settlement of fines should be done with a full three dimensional model that is capable of simulating a buoyant plume and includes all the processes affecting settlement, consolidation, re-suspension and erosion of material. Incipient motion tests of the fines will be to be undertaken in a hydraulics laboratory at various levels of consolidation for input into this modelling.

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APPENDIX 1.

**MALAGASY NATIONAL POLICY OF THE
ENVIRONMENT (PNE)**

The Malagasy National Policy of the Environment (PNE) determines the framework of the orientations to give to our environment as well as the principles which must be respected for its implementation ”.

This national policy of the environment proposes:

- **To stop the spiral of the degradation** in which Madagasikara is aspired;
- **To reconcile the Man and his environment** so that the present generation and those to come can live in total harmony; and
- **To integrate the environmental policy** in global development policies of the country.

All things considered, “the ambition of the PNE is not other than to reconcile these two entities to bring them to a symbiosis ”.

And this is why, no environmental action can be distinguished from a development action in favour of man.

This is why the concept of conservation cannot be dissociated from that of development. Indeed, “there cannot be conservation of the environment without development, the conservation having to be the fruit of a rational development in harmony with nature ”.

If the finality of our PNE is to 'reconcile the malagasy people with his environment ', its objectives are the following:

- To develop **human resources**
 1. by reinforcing **the sensibilization** and **the training** of the populations;
 2. by causing **the participation of the population** in particular by reinforcing the associative movements to supplement, to support or perfect **the capacity of public management**;
 3. by **“moralizing the public life”** compared to our culture, our legislation, our needs for development...
 4. by reinforcing **the topic “environment”** in general education programs
 5. and to develop the dies of **formation** and **research**;
 6. to exploit and develop any medium to pass **the “environment” message**.
- To promote a durable, equitable development and distributed well on the territory.
 1. by **inventorying** natural resources to manage them and judiciously plan their use;

2. by **saving** natural resources;
 3. in better **developing** the local natural resources;
 4. by **rehabilitating** and/or maintaining the natural fertility of the medium and by stimulating its capacity of resistance to diseases and parasites;
 5. by stressing particularly on **the little populated zones** with strong potential to be able to gradually relieve congestion where the demographic pressure on the resources is strong;
 6. by **referencing** the investments so that the latter ensure the perennity of the development without carrying damage to natural resources.
- **To rehabilitate, preserve and manage** the Malagasy biodiversity which is unique in the world and to support the development of ecological tourism.
 - **To improve the framework of life** of the rural and urban populations so that they can profit from a noticeable improvement of the daily living conditions.
 - To take care to maintain **the balances** between growth of the population and development of the resources.

To give the maximum of chance of success to this policy, the following conditions will have to be met beforehand:

- **To instigate** the institutional framework by insufflating a new spirit to the existing institutions and to make them become aware of their respective responsibilities for better preserving and managing the environment.
- **To disengage the State.** The role of the State is to lay down the policy, to develop the incentives necessary, to follow and evaluate the reactions. It remains **to the private operators - associations of users, ONG and private companies** - to preserve and emphasize the resources of the country.
- **To improve the tools** of control of the evolution of our environment, to refine our policy and to be able to act in convenient time.
- **To develop the research** finalized in the field of the environment.
- To lay down **a demography policy** in order to quantify and qualify the foreseeable real needs for the nation.
- **To cleanse the relations** between the man and his surroundings by solving the problems of land securisation.

The implementation of this policy requires **an institutional framework**, comprising a certain number of entities.

On the level of the natural environment, one notes since the last decades a continuous fall of the quality of the environment. The reported problems are made up mainly of:

- The problem of **water** pollution which starts to become increasingly alarming and which is due mainly to the absence of legislation and control on the pollutant emissions by industrial facilities, but also fast urbanization involving the appearance of shantytowns near lakes and rivers;
- Progressive reduction in the **forest cover**. Forests covered 24 to 28 % of the territory in 1950. It occupies no more than 16 to 17 % of the island today. Deforestation is especially caused by the clearings (resulting mainly from the practice of "tavy"), the bush fires lit by the stockbreeders to maintain the zones of pastures or by other people at various ends, like by the illicit forestry development in order to satisfying the increasing requirements of wood fuels, construction wood and sawlog.
- **Soil degradations** are worsened by the cultivation methods and other destroying and polluting activities. Thus, the phenomenon of erosion is directly related to the generalized destruction of the vegetable cover.
- There are many threats of degradation or **extinction** of fauna and flora accelerated by man, which probably involved the disappearance of many original species, often giant, like Aepyornis (Bird), dwarf Hippopotame, etc. Some wild animals flesh is appreciated by the Malagasy illegal export of protected species (tortoises, boïdés, etc.).
- **Natural cataclysms**, primarily the tropical cyclones, whose damage they cause are amplified by the harmful actions of man on nature.

The environmental damage can also be caused by human activities: In Madagascar, among the sectors having bonds with the environment, one can quote:

- **Agriculture:** This sector is mainly responsible for the degradation of the soils (chemical pollution by manures, irrigation, "tavy",...)
- **Fishing:** It contributes largely to the reduction in piscicultural stocks, by the overexploitation of these stocks and the use of destroying fishing tackles (nonselective fishing);
- **Industry:** The industrial activities are the principal sources of pollution on the environment: discharges of polluting gases in the atmosphere, waste solid, waste water of the factories;
- **Energy:** The energy sector conditions certain aspects of the environmental problems. Indeed, the domestic consumption of energy is characterized by the domination of wood fuels which leads to a continuous deforestation. Thus it is essential to develop other fuels and ameliorate the distribution of the production of energy in Madagascar.
- **Transport:** The road systems have considerable impacts on the environment: quality of the landscape, ecosystems natural, accidents (toxic spreadings of products...), noises, emission of polluting gases. Moreover, the outdatedness of a great number of travelling vehicles only amplify some of the problems quoted above.

Last but not least, the pressures on the environment are the fact of the population in general, because of various socio-economic problems:

- **An increase in the population** faster than the economic growth causes a certain tendency to the overexploitation of natural resources;
- **A bad distribution** of the population creates an accumulation of individuals in urban zones having thus enormous densities (up to 20.000 hab/km²); it brings up a certain number of environmental problems, like insalubrity, the deterioration of the quality of water and soils, the various types of pollution, the lack of hygiene and drainage work;
- **The low standard of living** of the major part of the population supports also the overexploitation and the qualitative and quantitative degradation of natural resources.

APPENDIX 2.

**ELEMENTS OF THE 1996 PROTOCOL TO THE LONDON
CONVENTION**

A2.1 OBJECTIVES

Contracting Parties shall individually and collectively protect and preserve the marine environment from all sources of pollution and take effective measures, according to their scientific, technical and economic capabilities, to prevent, reduce and where practicable eliminate pollution caused by dumping or incineration at sea of wastes or other matter.

A2.2 GENERAL OBLIGATIONS

Contracting Parties shall apply a precautionary approach to environmental protection from dumping of wastes or other matter whereby appropriate preventative measures are taken when there is reason to believe that wastes or other matter introduced into the marine environment are likely to cause harm even when there is no conclusive evidence to prove a causal relation between inputs and their effects.

Taking into account the approach that the polluter should, in principle, bear the cost of pollution, each Contracting Party shall endeavour to promote practices whereby those it has authorized to engage in dumping or incineration at sea bear the cost of meeting the pollution prevention and control requirements for the authorized activities, having due regard to the public interest.

In implementing the provisions of this Protocol, Contracting Parties shall act so as not to transfer, directly or indirectly, damage or likelihood of damage from one part of the environment to another or transform one type of pollution into another.

A2.3 DUMPING OF WASTES OR OTHER MATTER

Contracting Parties shall prohibit the dumping of any wastes or other matter with the exception of those below. The following wastes or other matter are those that may be considered for dumping being mindful of the Objectives and General Obligations of this Protocol.

- dredged material;
- sewage sludge;
- fish waste, or material resulting from industrial fish processing operations;
- vessels and platforms or other man-made structures at sea;
- inert, inorganic geological material;
- organic material of natural origin; and
- bulky items primarily comprising iron, steel, concrete and similarly unarmful materials for which the concern is physical impact.

The dumping of wastes or other matter listed above shall require a permit.

A2.4 ISSUANCE OF PERMITS AND REPORTING

Contracting Parties shall designate an appropriate authority or authorities to:

- issue permits in accordance with this Protocol;

- keep records of the nature and quantities of all wastes or other matter for which dumping permits have been issued and where practicable the quantities actually dumped and the location, time and method of dumping; and
- monitor individually, or in collaboration with other Contracting Parties and competent international organizations, the condition of the sea for the purposes of this Protocol.

A2.5 ASSESSMENT OF WASTES OR OTHER MATTER THAT MAY BE CONSIDERED FOR DUMPING

Contracting Parties shall adopt administrative or legislative measures to ensure that issuance of permits and permit conditions comply with the provisions (described below). Particular attention shall be paid to opportunities to avoid dumping in favour of environmentally preferable alternatives. Elements of the measures are described below:

A2.5.1 WASTE PREVENTION AUDIT

Feasibility of the following waste reduction/prevention techniques:

- product reformulation;
- clean production technologies;
- process modification;
- input substitution; and
- on-site, closed-loop recycling.

A2.5.2 CONSIDERATION OF WASTE MANAGEMENT OPTIONS

Applications to dump wastes or other matter shall demonstrate that appropriate consideration has been given to the following hierarchy of waste management options, which implies an order of increasing environmental impact:

- re-use;
- off-site recycling;
- destruction of hazardous constituents;
- treatment to reduce or remove the hazardous constituents; and
- disposal on land, into air and in water.

A2.5.3 CHEMICAL, PHYSICAL AND BIOLOGICAL PROPERTIES

A detailed description and characterization of the waste is an essential precondition for the consideration of alternatives and the basis for a decision as to whether a waste may be dumped. If a waste is so poorly characterized that proper assessment cannot be made of its potential impacts on human health and the environment, then that waste shall not be dumped.

Characterization of the wastes and their constituents shall take into account:

- origin, total amount, form and average composition;
- properties: physical, chemical, biochemical and biological;

- toxicity;
- persistence: physical, chemical and biological; and
- accumulation and bio-transformation in biological materials or sediments.

A2.5.3 DUMP-SITE SELECTION

Information required to select a dump-site shall include:

- physical, chemical and biological characteristics of the water-column and the seabed;
- location of amenities, values and other uses of the sea in the area under consideration;
- assessment of the constituent fluxes associated with dumping in relation to existing fluxes of substances in the marine environment; and
- economic and operational feasibility.

A2.5.4 ASSESSMENT OF POTENTIAL EFFECTS

Assessment of potential effects should lead to a concise statement of the expected consequences of the sea or land disposal options. It provides a basis for deciding whether to approve or reject the proposed disposal option and for defining environmental monitoring requirements.

The assessment for dumping should integrate information on waste characteristics, conditions at the proposed dump-site(s), fluxes, and proposed disposal techniques and specify the potential effects on human health, living resources, amenities and other legitimate uses of the sea. It should define the nature, temporal and spatial scales and duration of expected impacts based on reasonably conservative assumptions.

Each assessment should conclude with a statement supporting a decision to issue or refuse a permit for dumping.

A2.5.5 MONITORING

Monitoring is used to verify that permit conditions are met - compliance monitoring - and that the assumptions made during the permit review and site selection process were correct and sufficient to protect the environment and human health - field monitoring. It is essential that such monitoring programmes have clearly defined objectives.

A2.5.6 PERMIT AND PERMIT CONDITIONS

A decision to issue a permit should only be made if all impact evaluations are completed and the monitoring requirements are determined. The provisions of the permit shall ensure, as far as practicable, that environmental disturbance and detriment are minimized and the benefits maximized.

Any permit issued shall contain data and information specifying:

- the types and sources of materials to be dumped;
- the location of the dump-site(s);
- the method of dumping; and

- monitoring and reporting requirements.

Permits should be reviewed at regular intervals, taking into account the results of monitoring and the objectives of monitoring programmes. Review of monitoring results will indicate whether field programmes need to be continued, revised or terminated and will contribute to informed decisions regarding the continuance, modification or revocation of permits. This provides an important feedback mechanism for the protection of human health and the marine environment.

APPENDIX 3.

DETAILS OF AUTHORITY AND IAP LIAISON

Table A3-1 Details Of Authority And IAP Liaison

Name	Organization	Position	Time and place of meeting
Mr Christian Eddy Avellin	Societe D'Exploitation du Port de Toamasina	Port Captain	June 3rd 10h00 in office of the port captain
Mr Henri Paul Mananjara	Societe D'Exploitation du Port de Toamasina	Director of Infrastructure and Management	June 3rd 15h00 in office of the director
Ms Edwige Soavamoma	Ministry of the Interior	Provincial Director	June 3rd 16h00 in office of the minister
	Tanakala Village	Community elder	June 6th 10h00 at Tanakala village
	Eden Tourist Resort	Manager	June 6th 14h00 at Eden Resort
Dr William Rakotoarinivo	SAGE	Provincial Technical Coordinator	June 7th 08h30 at SAGE office
Mr Didier Barcelo	Réfrigépêche	Director General	June 8th 14h30 in office of director general

APPENDIX 4

PRDW APPENDICES & RAW DATA TABLES

Table A4-1 Dilution Results at a Water Depth of 10 m with an Ambient Current Speed of 0.02 m/s

Water Depth	10 m							
Current Vector	0.02 m/s at 45 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	12	5.9 hrs	18	13.5 hrs	25	28.8 hrs	32	100.0 hrs
Condition 2	18	5.9 hrs	28	13.5 hrs	32	28.8 hrs	46	100.0 hrs
Condition 3	41	5.9 hrs	153	13.5 hrs	362	28.8 hrs	737	100.0 hrs
Condition 4	89	5.9 hrs	232	13.5 hrs	548	28.8 hrs	1294	100.0 hrs
Condition 5	288	5.9 hrs	882	13.5 hrs	1403	28.8 hrs	4035	100.0 hrs

Water Depth	10 m							
Current Vector	0.02 m/s at 255 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	12	5.9 hrs	18	13.5 hrs	24	28.8 hrs	31	100.0 hrs
Condition 2	18	5.9 hrs	28	13.5 hrs	32	28.8 hrs	46	100.0 hrs
Condition 3	38	5.9 hrs	137	13.5 hrs	316	28.8 hrs	642	100.0 hrs
Condition 4	78	5.9 hrs	208	13.5 hrs	472	28.8 hrs	1152	100.0 hrs
Condition 5	300	5.9 hrs	893	13.5 hrs	1384	28.8 hrs	4004	100.0 hrs

Water Depth	10 m							
Current Vector	0.02 m/s at 345 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	12	5.9 hrs	18	13.5 hrs	25	28.8 hrs	32	100.0 hrs
Condition 2	18	5.9 hrs	28	13.5 hrs	32	28.8 hrs	46	100.0 hrs
Condition 3	41	5.9 hrs	152	13.5 hrs	361	28.8 hrs	735	100.0 hrs
Condition 4	89	5.9 hrs	232	13.5 hrs	547	28.8 hrs	1292	100.0 hrs
Condition 5	288	5.9 hrs	883	13.5 hrs	1402	28.8 hrs	4035	100.0 hrs

Condition 1 - Discharge = 4000 m³/h and Wind Speed = 0 m/s

Condition 2 - Discharge = 2000 m³/h and Wind Speed = 0 m/s

Condition 3 - Discharge = 4000 m³/h and Wind Speed = 3 m/s

Condition 4 - Discharge = 4000 m³/h and Wind Speed = 4 m/s

Condition 5 - Discharge = 4000 m³/h and Wind Speed = 10 m/s

Table A4-2 Dilution Results at a Water Depth of 10 m with an Ambient Current Speed of 0.1 m/s

Water Depth	10 m							
Current Vector	0.1 m/s at 45 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	182	1.2 hrs	209	2.7 hrs	247	5.8 hrs	568	20.0 hrs
Condition 2	328	1.2 hrs	389	2.7 hrs	483	5.8 hrs	1359	20.0 hrs
Condition 3	182	1.2 hrs	211	2.7 hrs	254	5.8 hrs	636	20.0 hrs
Condition 4	183	1.2 hrs	213	2.7 hrs	263	5.8 hrs	745	20.0 hrs
Condition 5	197	1.2 hrs	294	2.7 hrs	597	5.8 hrs	2538	20.0 hrs

Water Depth	10 m							
Current Vector	0.1 m/s at 255 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	186	1.2 hrs	216	2.7 hrs	255	5.8 hrs	580	20.0 hrs
Condition 2	338	1.2 hrs	402	2.7 hrs	499	5.8 hrs	1382	20.0 hrs
Condition 3	186	1.2 hrs	218	2.7 hrs	262	5.8 hrs	649	20.0 hrs
Condition 4	187	1.2 hrs	220	2.7 hrs	271	5.8 hrs	758	20.0 hrs
Condition 5	197	1.2 hrs	293	2.7 hrs	594	5.8 hrs	2521	20.0 hrs

Water Depth	10 m							
Current Vector	0.1 m/s at 345 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	214	1.2 hrs	243	2.7 hrs	285	5.8 hrs	617	20.0 hrs
Condition 2	393	1.2 hrs	462	2.7 hrs	562	5.8 hrs	1465	20.0 hrs
Condition 3	214	1.2 hrs	245	2.7 hrs	291	5.8 hrs	687	20.0 hrs
Condition 4	215	1.2 hrs	248	2.7 hrs	301	5.8 hrs	797	20.0 hrs
Condition 5	229	1.2 hrs	330	2.7 hrs	639	5.8 hrs	2618	20.0 hrs

* Time required to reach dilution

Condition 1 - Discharge = 4000 m³/h and Wind Speed = 0 m/s

Condition 2 - Discharge = 2000 m³/h and Wind Speed = 0 m/s

Condition 3 - Discharge = 4000 m³/h and Wind Speed = 3 m/s

Condition 4 - Discharge = 4000 m³/h and Wind Speed = 4 m/s

Condition 5 - Discharge = 4000 m³/h and Wind Speed = 10 m/s

Table A4-3 Dilution Results at a Water Depth of 10 m with an Ambient Current Speed of 0.5 m/s

Water Depth	10 m							
Current Vector	0.5 m/s at 45 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	142	0.2 hrs	242	0.5 hrs	484	1.2 hrs	1854	4.0 hrs
Condition 2	302	0.2 hrs	511	0.5 hrs	1020	1.2 hrs	3903	4.0 hrs
Condition 3	142	0.2 hrs	242	0.5 hrs	484	1.2 hrs	1855	4.0 hrs
Condition 4	142	0.2 hrs	242	0.5 hrs	485	1.2 hrs	1858	4.0 hrs
Condition 5	146	0.2 hrs	252	0.5 hrs	507	1.2 hrs	1947	4.0 hrs

Water Depth	10 m							
Current Vector	0.5 m/s at 255 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	124	0.2 hrs	212	0.5 hrs	422	1.2 hrs	1607	4.0 hrs
Condition 2	365	0.2 hrs	661	0.5 hrs	1363	1.2 hrs	5429	4.0 hrs
Condition 3	124	0.2 hrs	212	0.5 hrs	422	1.2 hrs	1608	4.0 hrs
Condition 4	125	0.2 hrs	212	0.5 hrs	422	1.2 hrs	1610	4.0 hrs
Condition 5	128	0.2 hrs	219	0.5 hrs	442	1.2 hrs	1687	4.0 hrs

Water Depth	10 m							
Current Vector	0.5 m/s at 345 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	124	0.2 hrs	188	0.5 hrs	322	1.2 hrs	1223	4.0 hrs
Condition 2	265	0.2 hrs	391	0.5 hrs	659	1.2 hrs	2480	4.0 hrs
Condition 3	124	0.2 hrs	188	0.5 hrs	322	1.2 hrs	1225	4.0 hrs
Condition 4	125	0.2 hrs	188	0.5 hrs	322	1.2 hrs	1227	4.0 hrs
Condition 5	128	0.2 hrs	196	0.5 hrs	339	1.2 hrs	1297	4.0 hrs

* Time required to reach dilution

Condition 1 - Discharge = 4000 m³/h and Wind Speed = 0 m/s
Condition 2 - Discharge = 2000 m³/h and Wind Speed = 0 m/s
Condition 3 - Discharge = 4000 m³/h and Wind Speed = 3 m/s
Condition 4 - Discharge = 4000 m³/h and Wind Speed = 4 m/s
Condition 5 - Discharge = 4000 m³/h and Wind Speed = 10 m/s

Table A4-4 Dilution Results at a Water Depth of 10 m with an Ambient Current Speed of 1.0 m/s

Water Depth	10 m							
Current Vector	1 m/s at 45 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	245	0.1 hrs	382	0.3 hrs	627	0.6 hrs	1374	2.0 hrs
Condition 2	458	0.1 hrs	729	0.3 hrs	1221	0.6 hrs	2716	2.0 hrs
Condition 3	245	0.1 hrs	382	0.3 hrs	627	0.6 hrs	1374	2.0 hrs
Condition 4	245	0.1 hrs	382	0.3 hrs	627	0.6 hrs	1374	2.0 hrs
Condition 5	246	0.1 hrs	384	0.3 hrs	631	0.6 hrs	1374	2.0 hrs

Water Depth	10 m							
Current Vector	1 m/s at 255 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	225	0.1 hrs	438	0.3 hrs	814	0.6 hrs	1922	2.0 hrs
Condition 2	288	0.1 hrs	691	0.3 hrs	1495	0.6 hrs	3799	2.0 hrs
Condition 3	225	0.1 hrs	438	0.3 hrs	814	0.6 hrs	1922	2.0 hrs
Condition 4	225	0.1 hrs	438	0.3 hrs	814	0.6 hrs	1922	2.0 hrs
Condition 5	226	0.1 hrs	440	0.3 hrs	819	0.6 hrs	1922	2.0 hrs

Water Depth	10 m							
Current Vector	1 m/s at 345 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	378	0.1 hrs	695	0.3 hrs	1220	0.6 hrs	2796	2.0 hrs
Condition 2	690	0.1 hrs	1336	0.3 hrs	2415	0.6 hrs	5619	2.0 hrs
Condition 3	378	0.1 hrs	695	0.3 hrs	1220	0.6 hrs	2796	2.0 hrs
Condition 4	378	0.1 hrs	695	0.3 hrs	1220	0.6 hrs	2796	2.0 hrs
Condition 5	380	0.1 hrs	699	0.3 hrs	1228	0.6 hrs	2796	2.0 hrs

* Time required to reach dilution

Condition 1 - Discharge = 4000 m³/h and Wind Speed = 0 m/s

Condition 2 - Discharge = 2000 m³/h and Wind Speed = 0 m/s

Condition 3 - Discharge = 4000 m³/h and Wind Speed = 3 m/s

Condition 4 - Discharge = 4000 m³/h and Wind Speed = 4 m/s

Condition 5 - Discharge = 4000 m³/h and Wind Speed = 10 m/s

Table A4-5 Dilution Results at a Water Depth of 20 m with an Ambient Current Speed of 0.02 m/s

Water Depth	20 m							
Current Vector	0.02 m/s at 45 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	31	5.9 hrs	45	13.5 hrs	66	28.8 hrs	82	100.0 hrs
Condition 2	55	5.9 hrs	62	13.5 hrs	72	28.8 hrs	120	100.0 hrs
Condition 3	78	5.9 hrs	207	13.5 hrs	522	28.8 hrs	1089	100.0 hrs
Condition 4	181	5.9 hrs	381	13.5 hrs	1139	28.8 hrs	2522	100.0 hrs
Condition 5	518	5.9 hrs	1713	13.5 hrs	3170	28.8 hrs	8515	100.0 hrs

Water Depth	20 m							
Current Vector	0.02 m/s at 255 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	32	5.9 hrs	45	13.5 hrs	66	28.8 hrs	82	100.0 hrs
Condition 2	55	5.9 hrs	62	13.5 hrs	72	28.8 hrs	120	100.0 hrs
Condition 3	77	5.9 hrs	197	13.5 hrs	488	28.8 hrs	1012	100.0 hrs
Condition 4	167	5.9 hrs	354	13.5 hrs	1003	28.8 hrs	2226	100.0 hrs
Condition 5	510	5.9 hrs	1678	13.5 hrs	2942	28.8 hrs	8363	100.0 hrs

Water Depth	20 m							
Current Vector	0.02 m/s at 345 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	31	5.9 hrs	45	13.5 hrs	65	28.8 hrs	81	100.0 hrs
Condition 2	55	5.9 hrs	62	13.5 hrs	72	28.8 hrs	120	100.0 hrs
Condition 3	78	5.9 hrs	205	13.5 hrs	518	28.8 hrs	1082	100.0 hrs
Condition 4	166	5.9 hrs	353	13.5 hrs	1000	28.8 hrs	2222	100.0 hrs
Condition 5	508	5.9 hrs	1675	13.5 hrs	2932	28.8 hrs	8352	100.0 hrs

* Time required to reach dilution

Condition 1 - Discharge = 4000 m³/h and Wind Speed = 0 m/s

Condition 2 - Discharge = 2000 m³/h and Wind Speed = 0 m/s

Condition 3 - Discharge = 4000 m³/h and Wind Speed = 3 m/s

Condition 4 - Discharge = 4000 m³/h and Wind Speed = 4 m/s

Condition 5 - Discharge = 4000 m³/h and Wind Speed = 10 m/s

Table A4-6 Dilution Results at a Water Depth of 20 m with an Ambient Current Speed of 0.1 m/s

Water Depth	20 m							
Current Vector	0.1 m/s at 45 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	66	1.2 hrs	85	2.7 hrs	133	5.8 hrs	431	20.0 hrs
Condition 2	128	1.2 hrs	162	2.7 hrs	253	5.8 hrs	810	20.0 hrs
Condition 3	67	1.2 hrs	87	2.7 hrs	142	5.8 hrs	472	20.0 hrs
Condition 4	68	1.2 hrs	92	2.7 hrs	155	5.8 hrs	529	20.0 hrs
Condition 5	93	1.2 hrs	178	2.7 hrs	410	5.8 hrs	1582	20.0 hrs

Water Depth	20 m							
Current Vector	0.1 m/s at 255 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	62	1.2 hrs	77	2.7 hrs	118	5.8 hrs	362	20.0 hrs
Condition 2	115	1.2 hrs	143	2.7 hrs	219	5.8 hrs	678	20.0 hrs
Condition 3	62	1.2 hrs	79	2.7 hrs	125	5.8 hrs	397	20.0 hrs
Condition 4	63	1.2 hrs	83	2.7 hrs	136	5.8 hrs	444	20.0 hrs
Condition 5	84	1.2 hrs	155	2.7 hrs	348	5.8 hrs	1313	20.0 hrs

Water Depth	20 m							
Current Vector	0.1 m/s at 345 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	75	1.2 hrs	96	2.7 hrs	155	5.8 hrs	528	20.0 hrs
Condition 2	146	1.2 hrs	189	2.7 hrs	309	5.8 hrs	1060	20.0 hrs
Condition 3	75	1.2 hrs	99	2.7 hrs	167	5.8 hrs	578	20.0 hrs
Condition 4	76	1.2 hrs	105	2.7 hrs	182	5.8 hrs	650	20.0 hrs
Condition 5	105	1.2 hrs	208	2.7 hrs	492	5.8 hrs	1955	20.0 hrs

* Time required to reach dilution

Condition 1 - Discharge = 4000 m³/h and Wind Speed = 0 m/s

Condition 2 - Discharge = 2000 m³/h and Wind Speed = 0 m/s

Condition 3 - Discharge = 4000 m³/h and Wind Speed = 3 m/s

Condition 4 - Discharge = 4000 m³/h and Wind Speed = 4 m/s

Condition 5 - Discharge = 4000 m³/h and Wind Speed = 10 m/s

Table A4-7 Dilution Results at a Water Depth of 20 m with an Ambient Current Speed of 0.5 m/s

Water Depth	20 m							
Current Vector	0.5 m/s at 45 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	325	0.2 hrs	467	0.5 hrs	844	1.2 hrs	3638	4.0 hrs
Condition 2	450	0.2 hrs	708	0.5 hrs	1358	1.2 hrs	6193	4.0 hrs
Condition 3	325	0.2 hrs	467	0.5 hrs	844	1.2 hrs	3642	4.0 hrs
Condition 4	325	0.2 hrs	468	0.5 hrs	845	1.2 hrs	3648	4.0 hrs
Condition 5	328	0.2 hrs	479	0.5 hrs	878	1.2 hrs	3842	4.0 hrs

Water Depth	20 m							
Current Vector	0.5 m/s at 255 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	269	0.2 hrs	398	0.5 hrs	759	1.2 hrs	3514	4.0 hrs
Condition 2	357	0.2 hrs	658	0.5 hrs	1376	1.2 hrs	6820	4.0 hrs
Condition 3	269	0.2 hrs	399	0.5 hrs	759	1.2 hrs	3518	4.0 hrs
Condition 4	269	0.2 hrs	399	0.5 hrs	760	1.2 hrs	3523	4.0 hrs
Condition 5	270	0.2 hrs	408	0.5 hrs	788	1.2 hrs	3710	4.0 hrs

Water Depth	20 m							
Current Vector	0.5 m/s at 345 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	376	0.2 hrs	591	0.5 hrs	1136	1.2 hrs	5215	4.0 hrs
Condition 2	618	0.2 hrs	1065	0.5 hrs	2144	1.2 hrs	10263	4.0 hrs
Condition 3	376	0.2 hrs	591	0.5 hrs	1137	1.2 hrs	5221	4.0 hrs
Condition 4	376	0.2 hrs	592	0.5 hrs	1138	1.2 hrs	5229	4.0 hrs
Condition 5	382	0.2 hrs	610	0.5 hrs	1187	1.2 hrs	5515	4.0 hrs

* Time required to reach dilution

Condition 1 - Discharge = 4000 m³/h and Wind Speed = 0 m/s

Condition 2 - Discharge = 2000 m³/h and Wind Speed = 0 m/s

Condition 3 - Discharge = 4000 m³/h and Wind Speed = 3 m/s

Condition 4 - Discharge = 4000 m³/h and Wind Speed = 4 m/s

Condition 5 - Discharge = 4000 m³/h and Wind Speed = 10 m/s

Table A4-8 Dilution Results at a Water Depth of 20 m with an Ambient Current Speed of 1.0 m/s

Water Depth	20 m							
Current Vector	1 m/s at 45 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	503	0.1 hrs	881	0.3 hrs	1719	0.6 hrs	7910	2.0 hrs
Condition 2	464	0.1 hrs	615	0.3 hrs	918	0.6 hrs	2530	2.0 hrs
Condition 3	503	0.1 hrs	881	0.3 hrs	1719	0.6 hrs	7912	2.0 hrs
Condition 4	503	0.1 hrs	881	0.3 hrs	1719	0.6 hrs	7913	2.0 hrs
Condition 5	505	0.1 hrs	885	0.3 hrs	1729	0.6 hrs	7968	2.0 hrs

Water Depth	20 m							
Current Vector	1 m/s at 255 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	157	0.1 hrs	310	0.3 hrs	519	0.6 hrs	1581	2.0 hrs
Condition 2	208	0.1 hrs	475	0.3 hrs	950	0.6 hrs	3092	2.0 hrs
Condition 3	157	0.1 hrs	310	0.3 hrs	519	0.6 hrs	1582	2.0 hrs
Condition 4	157	0.1 hrs	310	0.3 hrs	519	0.6 hrs	1582	2.0 hrs
Condition 5	157	0.1 hrs	311	0.3 hrs	522	0.6 hrs	1592	2.0 hrs

Water Depth	20 m							
Current Vector	1 m/s at 345 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	405	0.1 hrs	555	0.3 hrs	854	0.6 hrs	2421	2.0 hrs
Condition 2	578	0.1 hrs	922	0.3 hrs	1578	0.6 hrs	4742	2.0 hrs
Condition 3	405	0.1 hrs	555	0.3 hrs	854	0.6 hrs	2422	2.0 hrs
Condition 4	405	0.1 hrs	555	0.3 hrs	855	0.6 hrs	2422	2.0 hrs
Condition 5	406	0.1 hrs	558	0.3 hrs	859	0.6 hrs	2438	2.0 hrs

* Time required to reach dilution

Condition 1 - Discharge = 4000 m³/h and Wind Speed = 0 m/s

Condition 2 - Discharge = 2000 m³/h and Wind Speed = 0 m/s

Condition 3 - Discharge = 4000 m³/h and Wind Speed = 3 m/s

Condition 4 - Discharge = 4000 m³/h and Wind Speed = 4 m/s

Condition 5 - Discharge = 4000 m³/h and Wind Speed = 10 m/s

Table A4-9 Dilution Results at a Water Depth of 25 m with an Ambient Current Speed of 0.02 m/s

Water Depth	25 m							
Current Vector	0.02 m/s at 45 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	52	5.9 hrs	57	13.5 hrs	65	28.8 hrs	95	100.0 hrs
Condition 2	78	5.9 hrs	88	13.5 hrs	102	28.8 hrs	169	100.0 hrs
Condition 3	55	5.9 hrs	74	13.5 hrs	122	28.8 hrs	331	100.0 hrs
Condition 4	59	5.9 hrs	92	13.5 hrs	174	28.8 hrs	519	100.0 hrs
Condition 5	148	5.9 hrs	311	13.5 hrs	701	28.8 hrs	2960	100.0 hrs

Water Depth	25 m							
Current Vector	0.02 m/s at 255 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	51	5.9 hrs	57	13.5 hrs	65	28.8 hrs	95	100.0 hrs
Condition 2	78	5.9 hrs	88	13.5 hrs	102	28.8 hrs	168	100.0 hrs
Condition 3	55	5.9 hrs	73	13.5 hrs	122	28.8 hrs	329	100.0 hrs
Condition 4	59	5.9 hrs	92	13.5 hrs	174	28.8 hrs	518	100.0 hrs
Condition 5	152	5.9 hrs	312	13.5 hrs	701	28.8 hrs	2961	100.0 hrs

Water Depth	25 m							
Current Vector	0.02 m/s at 345 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	51	5.9 hrs	57	13.5 hrs	65	28.8 hrs	95	100.0 hrs
Condition 2	78	5.9 hrs	88	13.5 hrs	102	28.8 hrs	169	100.0 hrs
Condition 3	55	5.9 hrs	73	13.5 hrs	122	28.8 hrs	330	100.0 hrs
Condition 4	59	5.9 hrs	92	13.5 hrs	173	28.8 hrs	518	100.0 hrs
Condition 5	141	5.9 hrs	310	13.5 hrs	700	28.8 hrs	2958	100.0 hrs

* Time required to reach dilution

Condition 1 - Discharge = 4000 m³/h and Wind Speed = 0 m/s

Condition 2 - Discharge = 2000 m³/h and Wind Speed = 0 m/s

Condition 3 - Discharge = 4000 m³/h and Wind Speed = 3 m/s

Condition 4 - Discharge = 4000 m³/h and Wind Speed = 4 m/s

Condition 5 - Discharge = 4000 m³/h and Wind Speed = 10 m/s

Table A4-10 Dilution Results at a Water Depth of 25 m with an Ambient Current Speed of 0.1 m/s

Water Depth	25 m							
Current Vector	0.1 m/s at 45 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	105	1.2 hrs	128	2.7 hrs	180	5.8 hrs	552	20.0 hrs
Condition 2	222	1.2 hrs	266	2.7 hrs	367	5.8 hrs	1085	20.0 hrs
Condition 3	106	1.2 hrs	130	2.7 hrs	189	5.8 hrs	609	20.0 hrs
Condition 4	108	1.2 hrs	134	2.7 hrs	202	5.8 hrs	690	20.0 hrs
Condition 5	131	1.2 hrs	222	2.7 hrs	472	5.8 hrs	2112	20.0 hrs

Water Depth	25 m							
Current Vector	0.1 m/s at 255 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	97	1.2 hrs	116	2.7 hrs	158	5.8 hrs	465	20.0 hrs
Condition 2	243	1.2 hrs	286	2.7 hrs	379	5.8 hrs	1040	20.0 hrs
Condition 3	98	1.2 hrs	118	2.7 hrs	166	5.8 hrs	512	20.0 hrs
Condition 4	98	1.2 hrs	121	2.7 hrs	177	5.8 hrs	578	20.0 hrs
Condition 5	117	1.2 hrs	192	2.7 hrs	398	5.8 hrs	1733	20.0 hrs

Water Depth	25 m							
Current Vector	0.1 m/s at 345 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	123	1.2 hrs	151	2.7 hrs	211	5.8 hrs	648	20.0 hrs
Condition 2	265	1.2 hrs	322	2.7 hrs	445	5.8 hrs	1331	20.0 hrs
Condition 3	125	1.2 hrs	153	2.7 hrs	222	5.8 hrs	714	20.0 hrs
Condition 4	126	1.2 hrs	157	2.7 hrs	236	5.8 hrs	808	20.0 hrs
Condition 5	149	1.2 hrs	253	2.7 hrs	543	5.8 hrs	2469	20.0 hrs

* Time required to reach dilution

Condition 1 - Discharge = 4000 m³/h and Wind Speed = 0 m/s

Condition 2 - Discharge = 2000 m³/h and Wind Speed = 0 m/s

Condition 3 - Discharge = 4000 m³/h and Wind Speed = 3 m/s

Condition 4 - Discharge = 4000 m³/h and Wind Speed = 4 m/s

Condition 5 - Discharge = 4000 m³/h and Wind Speed = 10 m/s

Table A4-11 Dilution Results at a Water Depth of 25 m with an Ambient Current Speed of 0.5 m/s

Water Depth	25 m							
Current Vector	0.5 m/s at 45 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	313	0.2 hrs	444	0.5 hrs	806	1.2 hrs	3485	4.0 hrs
Condition 2	434	0.2 hrs	674	0.5 hrs	1299	1.2 hrs	5925	4.0 hrs
Condition 3	313	0.2 hrs	445	0.5 hrs	807	1.2 hrs	3488	4.0 hrs
Condition 4	314	0.2 hrs	445	0.5 hrs	808	1.2 hrs	3494	4.0 hrs
Condition 5	317	0.2 hrs	456	0.5 hrs	838	1.2 hrs	3678	4.0 hrs

Water Depth	25 m							
Current Vector	0.5 m/s at 255 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	262	0.2 hrs	389	0.5 hrs	744	1.2 hrs	3438	4.0 hrs
Condition 2	351	0.2 hrs	645	0.5 hrs	1354	1.2 hrs	6678	4.0 hrs
Condition 3	262	0.2 hrs	389	0.5 hrs	745	1.2 hrs	3441	4.0 hrs
Condition 4	262	0.2 hrs	389	0.5 hrs	745	1.2 hrs	3446	4.0 hrs
Condition 5	263	0.2 hrs	398	0.5 hrs	774	1.2 hrs	3630	4.0 hrs

Water Depth	25 m							
Current Vector	0.5 m/s at 345 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	368	0.2 hrs	572	0.5 hrs	1105	1.2 hrs	5085	4.0 hrs
Condition 2	589	0.2 hrs	1037	0.5 hrs	2095	1.2 hrs	10022	4.0 hrs
Condition 3	369	0.2 hrs	572	0.5 hrs	1106	1.2 hrs	5091	4.0 hrs
Condition 4	369	0.2 hrs	572	0.5 hrs	1108	1.2 hrs	5098	4.0 hrs
Condition 5	375	0.2 hrs	592	0.5 hrs	1154	1.2 hrs	5378	4.0 hrs

* Time required to reach dilution

Condition 1 - Discharge = 4000 m³/h and Wind Speed = 0 m/s
Condition 2 - Discharge = 2000 m³/h and Wind Speed = 0 m/s
Condition 3 - Discharge = 4000 m³/h and Wind Speed = 3 m/s
Condition 4 - Discharge = 4000 m³/h and Wind Speed = 4 m/s
Condition 5 - Discharge = 4000 m³/h and Wind Speed = 10 m/s

Table A4-12 Dilution Results at a Water Depth of 25 m with an Ambient Current Speed of 1.0 m/s

Water Depth	25 m							
Current Vector	1 m/s at 45 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	472	0.1 hrs	835	0.3 hrs	1648	0.6 hrs	7576	2.0 hrs
Condition 2	418	0.1 hrs	521	0.3 hrs	733	0.6 hrs	1912	2.0 hrs
Condition 3	472	0.1 hrs	836	0.3 hrs	1648	0.6 hrs	7577	2.0 hrs
Condition 4	472	0.1 hrs	836	0.3 hrs	1648	0.6 hrs	7578	2.0 hrs
Condition 5	474	0.1 hrs	840	0.3 hrs	1658	0.6 hrs	7632	2.0 hrs

Water Depth	25 m							
Current Vector	1 m/s at 255 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	154	0.1 hrs	282	0.3 hrs	429	0.6 hrs	1223	2.0 hrs
Condition 2	292	0.1 hrs	433	0.3 hrs	763	0.6 hrs	2367	2.0 hrs
Condition 3	154	0.1 hrs	282	0.3 hrs	429	0.6 hrs	1223	2.0 hrs
Condition 4	154	0.1 hrs	282	0.3 hrs	429	0.6 hrs	1223	2.0 hrs
Condition 5	154	0.1 hrs	283	0.3 hrs	432	0.6 hrs	1232	2.0 hrs

Water Depth	25 m							
Current Vector	1 m/s at 345 deg							
Distance to Bank	425m		975m		2075m		7200m	
	Dilution	Time*	Dilution	Time*	Dilution	Time*	Dilution	Time*
Condition 1	362	0.1 hrs	467	0.3 hrs	682	0.6 hrs	1852	2.0 hrs
Condition 2	502	0.1 hrs	745	0.3 hrs	1217	0.6 hrs	3582	2.0 hrs
Condition 3	362	0.1 hrs	467	0.3 hrs	682	0.6 hrs	1852	2.0 hrs
Condition 4	362	0.1 hrs	467	0.3 hrs	682	0.6 hrs	1853	2.0 hrs
Condition 5	362	0.1 hrs	468	0.3 hrs	685	0.6 hrs	1865	2.0 hrs

* Time required to reach dilution

Condition 1 - Discharge = 4000 m³/h and Wind Speed = 0 m/s
Condition 2 - Discharge = 2000 m³/h and Wind Speed = 0 m/s
Condition 3 - Discharge = 4000 m³/h and Wind Speed = 3 m/s
Condition 4 - Discharge = 4000 m³/h and Wind Speed = 4 m/s
Condition 5 - Discharge = 4000 m³/h and Wind Speed = 10 m/s

VOLUME I: PHYSICAL APPENDICES

APPENDIX 11-1

VISUAL AESTHETICS BASELINE

Submitted to:

Dynatec Corporation

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1 INTRODUCTION

A baseline study of visual aesthetics resources was conducted for the Ambatovy Project (the project) to establish existing conditions at all project sites and to assist in the Environmental Assessment (EA) for visual aesthetics. Studies of visual aesthetics investigate beauty and the psychological responses to appearances. Under baseline conditions, perceptions of aesthetics are affected by:

- landform shapes, slopes and diversity;
- presence of water features;
- presence of vegetation and the texture, colour and diversity of the vegetation within the landscape;
- the level of modification of the landscape and appearance of disturbances, whether they contrast strongly or blend partially with the scenic background landscape;
- viewing distance between observer and subject;
- viewing orientation; for example, is the observer usually looking directly at the landscape;
- viewing frequency and duration; and
- viewer perception; for example, what is expected and what is considered visually attractive or unattractive.

Visual aesthetics is an issue that may be of importance to local residents, or tourists and other visitors.

2 METHODS

To document baseline visual aesthetics conditions in each project location, field visits were conducted and baseline photographs were taken from key viewpoints.

Topographic and geologic maps and Digital Elevation Model (DEM) data were used to develop an understanding of baseline topography and geomorphology, as described in Volume I, Appendix 1.1 (Topography and Geomorphology).

The flora in each project area (Volume J, Appendix I [Flora]) was documented in detailed floristic surveys.

The locations of residents near each project area (Volume K, Appendix 1.1 [Socioeconomics]) were also documented in extensive socioeconomic investigations.

Based on the data collected, baseline viewsheds for each project area have been described. The visual aesthetics qualities for several key viewpoints have been summarized at each project location, focusing on viewpoints that the greatest numbers of people may visit, such as cities, villages, ecotourism locations, roads and trails.

3 RESULTS

3.1 GENERAL

The landscape of Madagascar is largely rural but has been shaped over a long period of time by climate, underlying geology, structural features, erosional processes and human activity. Topographic characteristics, vegetation cover characteristics, and levels of human activity vary considerably between different project areas.

3.2 MINE

The ore bodies are located in a densely forested area. The remnants of an eroded plateau make up the two ore bodies. To the west, the plateau is flanked by a broad alluvial plain of the Mangoro River. To the east is the Torotorofotsy – Mokaranana wetlands system and forested hills. A general aerial overview of the area is provided in Photograph 1 in Volume I-11.1, Attachment 1.

Presently, views of the mine area from all directions are dominated by lush vegetation and are considered scenic. However, under baseline conditions disturbance in the area is already apparent due to past exploratory activity. When viewed at close range, it is clear that the vegetation in the Ambatovy and Analamay ore bodies area is naturally stunted. The Analamay ore body also has especially sparse vegetation due to recent fires.

Views of the mine area are possible from several areas in the surrounding landscape, including high hilltop areas in Mantadia National Park, the Torotorofotsy Ramsar Site, roadways such as Route Nationale (RN) 44, and various small towns and agricultural areas. However, in heavily vegetated areas, such as the forested corridor to the north, south and east of the future mine site, there are few good viewpoints toward the site.

West of the future mine location, along the proposed water intake line from the Mangoro River, the topography flattens and valley bottoms widen. Vegetation in this corridor is largely human-influenced. This corridor is highly visible from RN44 and several small villages.

The baseline viewshed of the mine is defined as all land locations that offer a direct view toward the future mine site. This includes the areas immediately surrounding the site, and nearby hillsides and hilltops that are high enough to offer views into the valleys being developed for the project. However, the steep,

rolling topography around the site almost entirely obscures views from 3 km away or more. Thus key viewpoints toward the future mine location are generally within a short distance of the planned development. Sample views of the Ambatovy and Analamay areas are presented in Volume I-11.1, Attachment 1, Photographs 2 and 3. Since public access to these areas will be very limited during mine operations, the mine site areas are not candidates for key viewpoints for the impact assessment. Key viewpoints for this assessment must be accessible to the public during project activity and must be within the project viewshed. The key viewpoints are summarized in Table 11.1-1. Baseline views from key viewpoints M1 to M5 are presented in Volume I-II.1, Attachment 1, Photographs 4 through 8.

Table 11.1-1 Key Viewpoints: Mine Site

Viewpoint Number	Viewpoint Name	GPS location (UTM Zone 39S)	Possible Viewers	Baseline View Characteristics
M1	Torotorofotsy Wetlands	E 222731 N 7910838	local residents ecotourists	relatively natural and undisturbed; heavy vegetation cover
M2	RN44	E 208407 N 7913684	local residents travellers and tourists	human-influenced corridor with extensive land use; views of primary forest in distance
M3	mine access road	E 210854 N 7912564	local residents	partially disturbed and cleared by human use; patches of primary forest visible
M4	northwest view at mine near access corridor and agricultural area	E 213954 N 913870	local residents	foreground area is cleared for human use; background consists of primary or secondary zonal and azonal forests
M5	southeast view at mine near access corridor and agricultural area	E 214088 N 913007	local residents	foreground area is cleared for human use; background consists of primary or secondary zonal and azonal forests

3.3 PIPELINE

The pipeline route traverses a variety of landscapes, including the central highlands and coastal plains. It crosses through the Torotorofotsy wetlands complex, adjacent to Mantadia Park in some locations, and parallels a portion of the Madarail system for a short distance. An aerial overview of the Torotorofotsy wetlands, showing part of the future pipeline route, is provided in Volume I-11.1, Attachment 1, Photograph 9. The pipeline will have many potential viewpoints along its route, and passes through scenic landscapes characterized by steep topographic features, small and large waterways, and vegetation ranging from primary forest to barren dune areas.

Key viewpoints along the future pipeline location fall within a short distance of the planned development, in general, because steep, irregular topography in surrounding areas tends to obscure views of the route. Key viewpoints for this assessment must be used frequently by people (towns, villages and access routes) and must be close enough to the future right-of-way to observe it. Key viewpoints in areas where the pipeline is likely to be above ground may be especially important. The key viewpoints are summarized in Table 11.1-2. The baseline views from key viewpoints SP1 through SP4 are shown in Volume I-11.1, Attachment 1, Photographs 10 to 13.

Table 11.1-2 Key Viewpoints: Slurry Pipeline Route

Viewpoint Number	Viewpoint Name	GPS Location (UTM Zone 39S)	Possible Viewers	Baseline View Characteristics
SP1	Torotorofotsy Wetlands	E 222731 N 7910838	local residents ecotourists	relatively natural and undisturbed; heavy vegetation cover
SP2	village of Sahavolo	E 274500 N 7930600	local residents	at village of Sahavolo along pipeline, characterized by agricultural land use areas
SP3	Vohitra River crossing	E 337367 N 7955595	local residents	relatively natural with heavy vegetation cover; small town adjacent
SP4	Ivondro River crossing	E 0316115 N 7980851	local residents	wide, scenic river with moderate bank vegetation cover, prominent signs of human use including nearby road corridor/bridge

3.4 PROCESS PLANT

The process plant is located near Antanandava, on the edge of Toamasina, in an area characterized by flat, relatively open coastal topography. A general aerial overview of the process plant site is provided in Volume I-11.1, Attachment 1, Photograph 14. In the photograph, the future plant site is in the foreground, with Toamasina to the north in the background. The area has sparsely vegetated sand dunes and several ponds, and has been impacted in many areas by prior land clearing. Vegetation varies from grasses to moderately sized shrubs and some trees.

Signs of existing development in the immediate area include huts and powerlines. Within 3 km of the site, there is existing heavy industry, including the Galana refinery. Immediately surrounding the future plant location, the relatively sparse vegetation and flat topography allows for good views of the site from all directions. However, the site becomes less visible as distance increases. To the east, the Pangalanes Canal passes the site; to the west, highway RN2 passes within 1 km. However, neither of these routes have prominent views of the

process plant area. The village of Amboakarivo is located 2 km south of the site, and Toamasina is within 4 km to the northeast.

Key viewpoints toward the future process plant site fall within a few kilometres of the planned development, because, even in this relatively open area, vegetation and existing development activity tend to obscure views of the site from long distances. As for other project sites, key viewpoints for this assessment must be used frequently by people (towns, villages and access routes) and must be close enough to the site to observe it. The key viewpoints are summarized in Table 11.1-3. Baseline views from viewpoints PP1, PP2, PP3 and PP4 are shown in Volume I-11.1, Attachment 1, Photographs 15 through 18, respectively.

Table 11.1-3 Key Viewpoints: Process Plant Site

Viewpoint Number	Viewpoint Name	GPS Location (UTM Zone 39S)	Possible Viewers	Baseline View Characteristics
PP1	Toamasina (south end) along rail corridor	E 328021 N 7987857	local residents tourists and travellers	heavily human-influenced urban area with residential, industrial and agricultural elements
PP2	Amboakarivo Road (from south of plant)	E 0327374 N 7986213	local residents	village roadway in natural setting, well maintained and scenic
PP3	from west of plant	E 0326108 N 7987111	local residents	sparse vegetation
PP4	from north of plant	E 0326466 N 7987495	local residents	sparse vegetation

3.5 TAILINGS FACILITY

A series of three valleys west of Toamasina make up the area of the planned tailings facility. The valleys are characterized by moderately steep, partially forested hillsides (valley walls) which descend into flat, wide valley floors. The highest elevation within the valleys is 90 meters above sea level (masl) at the western end, and the lowest elevation is 4 masl, in the far eastern portion of the site. The valley floors, in particular the wide, wet floor of the northern valley, have been developed into rice paddies. A few small communities are located within this landscape. In general, the views of the area may be perceived differently by different people; the area has a relatively natural appearance and is only sparsely occupied but is, in fact, heavily modified by historical human use. Vegetation in the area tends to be lush in valley bottoms, but sparse on hillsides.

A general aerial overview of the tailings area is provided in Photograph 19 in Volume I-11.1, Attachment 1. The viewshed for the site is relatively small due

to the irregular, hilly topography characterizing the area. Therefore, key viewpoints toward the future tailings facility location fall within a short distance of the planned development. The valleys are not highly visible from external viewpoints such as Toamasina, Antanandava and the highway route (RN2).

Most of the tailings site areas are not candidates for key viewpoints for the impact assessment because public access in these areas will be very limited during facility operations. The key viewpoints are summarized in Table 11.1-4. Baseline views from viewpoints TF1, TF2, TF3 and TF4 are shown in Volume I-11.1, Attachment 1, Photographs 20 through 23, respectively.

Table 11.1-4 Key Viewpoints: Tailings Facility Area

Viewpoint Number	Viewpoint Name	GPS Location (UTM Zone 39S)	Possible Viewers	Baseline View Characteristics
TF1	Highway (RN2) north of intersection with ridge road	E 327489 N 7992792	local residents tourists and travellers	human-influenced corridor with residential, industrial and agricultural elements and areas of secondary-growth forests
TF2	Antanandava (at bridge facing West)	E 325027 N 7989335	local residents	village in natural setting, well maintained, rustic
TF3	ridge road route facing central tailings basin area	E 324271 N 7989857	local residents	sparse secondary vegetation, eucalyptus woodlots, agriculture
TF4	ridge road route facing north tailings basin area	E 324008 N 7990051	local residents	sparse secondary vegetation, eucalyptus woodlots, agriculture

3.6 PORT

An aerial overview of the existing port at Toamasina is provided in Photograph 24 in Volume I-11.1, Attachment 1. The port is planned in a highly visible location at Toamasina. However, the area is already highly urbanized and has a variety of existing industrial development, including the existing port. Despite the industrial nature of the site, views of the existing port are relatively scenic, as they occur over a wide bay at the waterfront of Toamasina. Groups of people likely to be viewing the port include local residents, boaters and tourists.

The key viewpoints for the future port expansion are located in the heavily populated city of Toamasina. The most prominent views will occur from immediately adjacent coastal areas. The key viewpoints are summarized in Table 11.1-5. The baseline views from viewpoints P1 and P2 are presented in Volume I-11.1, Attachment 1, Photographs 25 and 26.

Table 11.1-5 Key Viewpoints: Port Area

Viewpoint Number	Viewpoint Name	GPS Location (UTM Zone 39S)	Possible Viewers	Baseline View Characteristics
P1	Toamasina shoreline	E 332664 N 7992049	local residents tourists and travellers	urban area with existing industrial port
P2	Toamasina shoreline	E 332357 N 7992032	local residents tourists and travellers	urban area with existing industrial port

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PHOTOGRAPHS



Photograph 1 Aerial Overview of Mine, Looking Northeast



Photograph 2 Close Proximity View of Ambatovy Central, View to West



Photograph 3: Close Proximity View of Analamay West, View to Southwest



A wide-angle photograph of a grassy field with a line of trees in the middle ground and hills in the background under a cloudy sky. The field is covered in green grass with some patches of bare earth. A dense line of green trees and shrubs runs horizontally across the middle of the frame. In the background, there are rolling hills and mountains under a bright, overcast sky with some light clouds.

January 2006



Photograph 6 **View Toward Future Mine Location from Mine Access Road
(Viewpoint M3)**



Photograph 7 **Ambatovy West: View to the Northwest from Mine Access Road
(Viewpoint M4)**



Photograph 8 Ambatovy West: View to the Southeast (Viewpoint M5)



**Photograph 9 Aerial Overview of Torotorofotsy Wetlands Looking northwest
Toward Future Pipeline Route**



Photograph 10 View to the Northwest at Torotorofotsy Wetland (Viewpoint SP1)



Photograph 11 View Toward Future Pipeline Location at Sahavolo Village (Viewpoint SP2)



Photograph 12 View of Vohitra River at Potential Crossing Location (Viewpoint SP3)



Photograph 13 View of Ivondro River at Potential Crossing Location (Viewpoint SP4)



Photograph 14 Aerial Overview of Process Plant Site (Foreground), Looking North



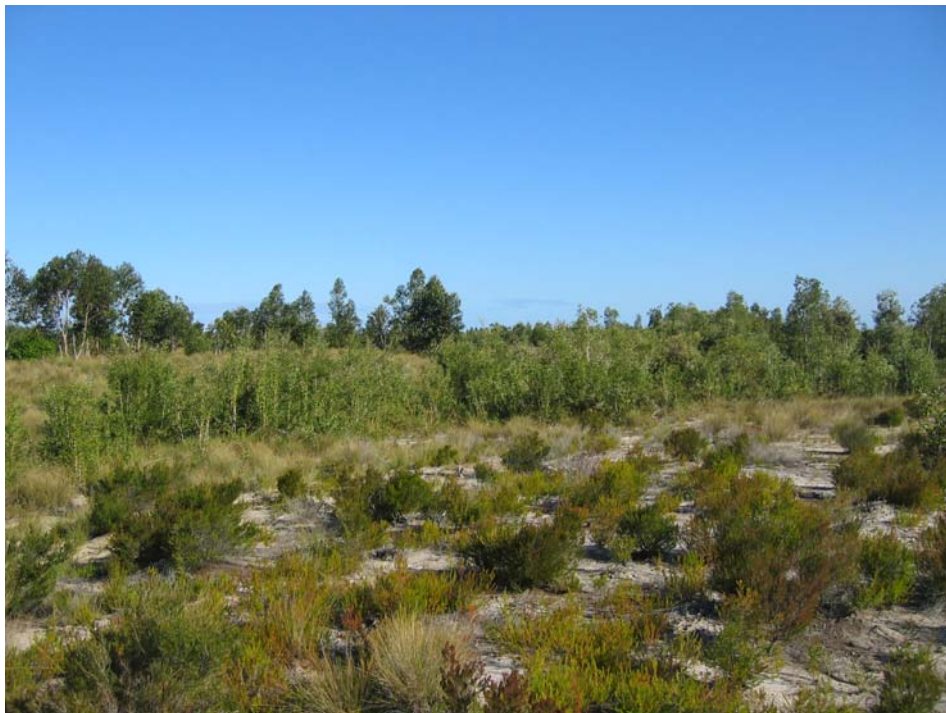
**Photograph 15 View to Southwest from Rail Route Toward Plant Site
Across the Pangalanes Canal (Viewpoint PP1)**



Photograph 16 View to the North at road to Amboakarivo (Viewpoint PP2)



**Photograph 17 View to the East at the West Side of the Future Plant Location
(Viewpoint PP3)**



**Photograph 18 View to the South at the North Side of the Future Plant Location
(Viewpoint PP4)**



Photograph 19 Aerial Overview of Basins at the Planned Location of the Tailings Facility (Middle Distance), Looking West



Photograph 20 View Toward Future Tailings Facility from RN2 (Viewpoint TF1)



Photograph 21 View to the West from Antanandava Bridge (Viewpoint TF2)



Photograph 22 Typical View in the Valley Proposed for Central Tailings Basin (Viewpoint TF3)



**Photograph 23 Typical View in the Valley Proposed for North Tailings Basin
(Viewpoint TF4)**



Photograph 24 Aerial Overview of the Existing Port at Toamasina, Facing South



Photograph 25 Typical View of the Port from Toamasina (Viewpoint P1)



Photograph 26 View of Port From Beach of Toamasina (Viewpoint P2)