Volume E 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

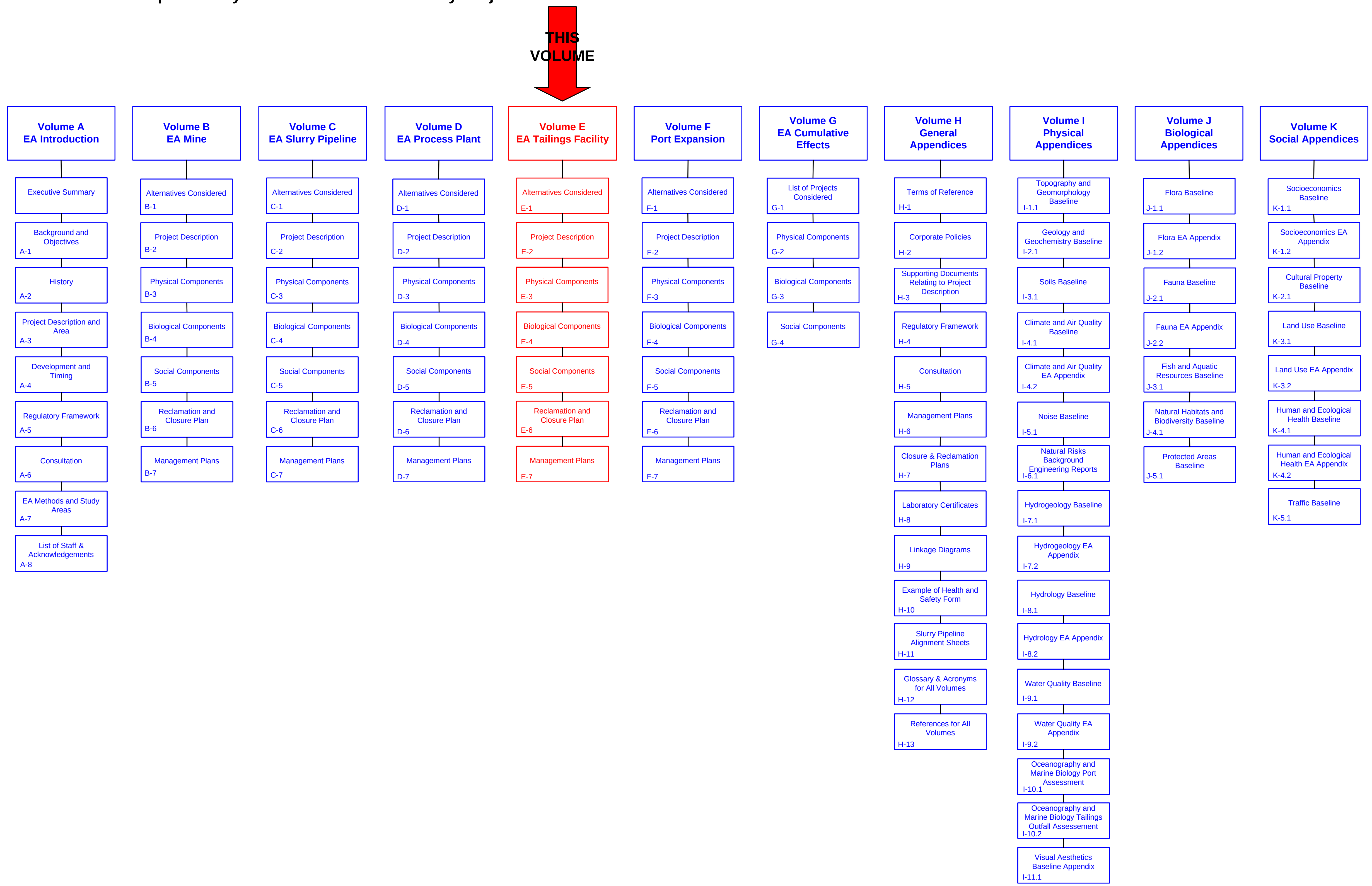
Volume A introduces the EA and contains study area and methodological information pertaining to all disciplines and all project components.

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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1 ALTERNATIVES CONSIDERED

An evaluation of tailings facility site alternatives in both the Brickaville and Toamasina areas was undertaken for the scoping portion of the Ambatovy Project (the project) development. The Brickaville area was initially investigated as the location for the plant site, leading to identification of potential tailings sites in the vicinity. The Toamasina area was then reviewed and selected as the preferential area for the plant site location. Subsequently, various potential sites for tailings disposal in the Toamasina area were identified. Table 5.1-1 provides a site comparison summary for the alternatives that were considered. The sites were first compared in terms of their:

- total capacity for tailings;
- storage efficiency;
- existing land use;
- foundation conditions;
- access and elevation;
- downstream risks; and
- watershed management.

As all sites were in largely man-modified habitats, flora and fauna considerations were not taken into account at this level of analysis.

Figures 1-1 and 1-2 present the potential tailings areas identified in the Brickaville and Toamasina areas during site visits.

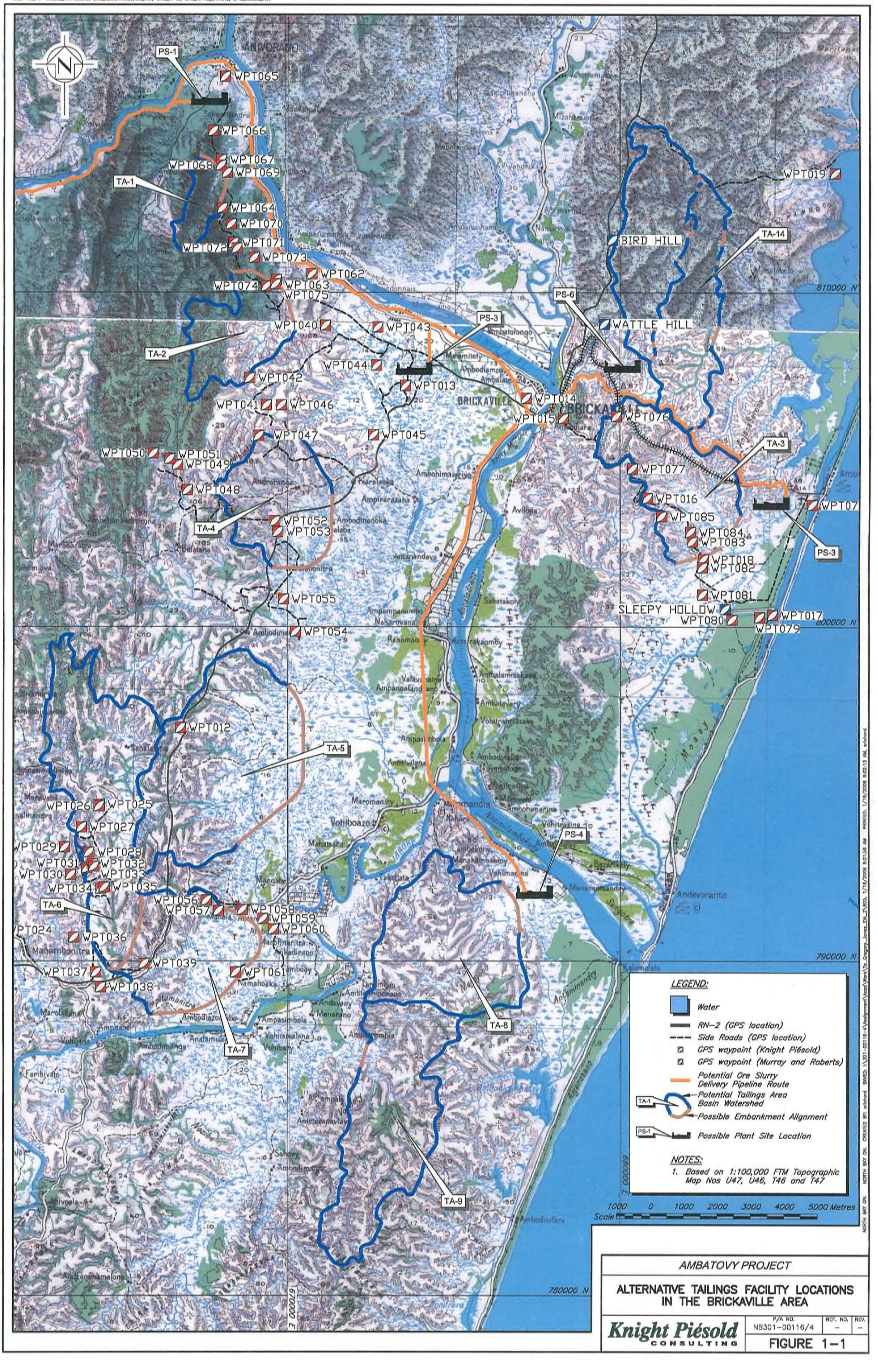
Table 1-1 Evaluation of Alternative Tailings Facility Locations

Site	Location	Capacity	Efficiency	Land Use	Conditions	Access and Elevation	Risks
Brickaville							
TA-1	west of Brickaville and south of Anivorano near PS-1	inadequate	low - valley type	small-scale agriculture and fish farming	expected to be relatively impermeable and competent	reasonable access along existing road up to elev. 100 m	village of Anivorano and Rianila River
TA-2	west of Brickaville and PS-2	barely sufficient	low - valley type	large-scale agriculture at least 100 ha and villages	expected to be relatively impermeable and competent	good access along existing roads to elev. 50 m	village to north and Rianila River
TA-3	east of Brickaville and west of PS-3	sufficient	low - valley type	limited small-scale agriculture around valley, and railway	pervious alluvium in valley base requiring basin liner	reasonable access along existing road to elev. 40 m	villages along coastal area and Pangalanes Canal
TA-4	southwest of Brickaville	barely sufficient	poor - sidehill type	large-scale agriculture and abundant villages	potentially pervious alluvium requiring basin liner	reasonable access along existing roads to elev. 40 m	villages, agricultural areas and Rianila River
TA-5	south of Brickaville	barely sufficient	poor - sidehill type	large-scale agriculture and abundant villages	potentially pervious alluvium requiring basin liner	reasonable access along existing roads to elev. 40 m	villages, agricultural areas and Rianila River
TA-6	southwest of Brickaville	sufficient	good - valley type	small-scale agriculture and forestry	expected to be relatively impermeable and competent	reasonable access along existing roads to elev. 40 m	villages, agricultural areas and Iaroka River
TA-7	south of Brickaville	barely sufficient	poor - sidehill type	large-scale agriculture and abundant villages	potentially pervious alluvium requiring basin liner	reasonable access along existing roads to elev. 40 m	villages, agricultural areas and Rianila River
TA-8/ TA-9	southeast of Brickaville near PS-4	barely sufficient	low - valley type	small-scale agriculture	potentially pervious alluvium requiring basin liner	poor access to elev. 40 m	village and Rianila River
TA-14	northeast of Brickaville and north of PS-6	barely sufficient	good - valley type	small-scale agriculture and small villages	potential for pervious foundations to east requiring basin liner	Good Access to elev. 75 m	villages / tourist areas on Lac Rasoabe

Table 1-1 Evaluation of Alternative Tailings Facility Locations (continued)

Site	Location	Capacity	Efficiency	Land Use	Conditions	Access and Elevation	Risks
Toamasina							
TA-10/ TA-11	west of Toamasina and PS-5	sufficient	medium/good - valley type	medium-scale agriculture and small villages	expected to be relatively impermeable and competent	good access to elev. 45 m	villages and discharge to south into Ivondro River
TA-12/ TA13	west of Toamasina and PS-5	insufficient	medium/good - valley type	medium-scale agriculture and large villages	expected to be relatively impermeable and competent	good access to elev. 45 m	villages/agricultural areas and discharge to north into Onibe River watershed
Ring Dyke	south of Toamasina near PS-5	barely sufficient	very poor - no natural containment	designated industrial area	pervious alluvium requiring basin liner	good access to elev. 35 m.	adjacent town of Toamasina and Pangalanes Canal
South Valley	west of Toamasina and PS-5 and south of TA-10/11	sufficient	poor - valley type	medium-scale agriculture and large villages in lower valley	expected to be relatively impermeable and competent	good access to elev. 45 m.	villages/agricultural areas and discharge south to Ivondro River
West of TA-10/11	west of Toamasina and PS-5	insufficient if only one valley developed	poor - valley type but limited storage	small-scale agriculture and small villages	expected to be relatively impermeable and competent	no access and topography as high as elev. 200 m	villages/agricultural areas and discharge south to Ivondro River

XREF FILE : Mosaic_1to100000; Site_Reconnaissance_Rev; GPS_WPTS; GPS_WPTS_OTHERS; GPS_Roads_Rev



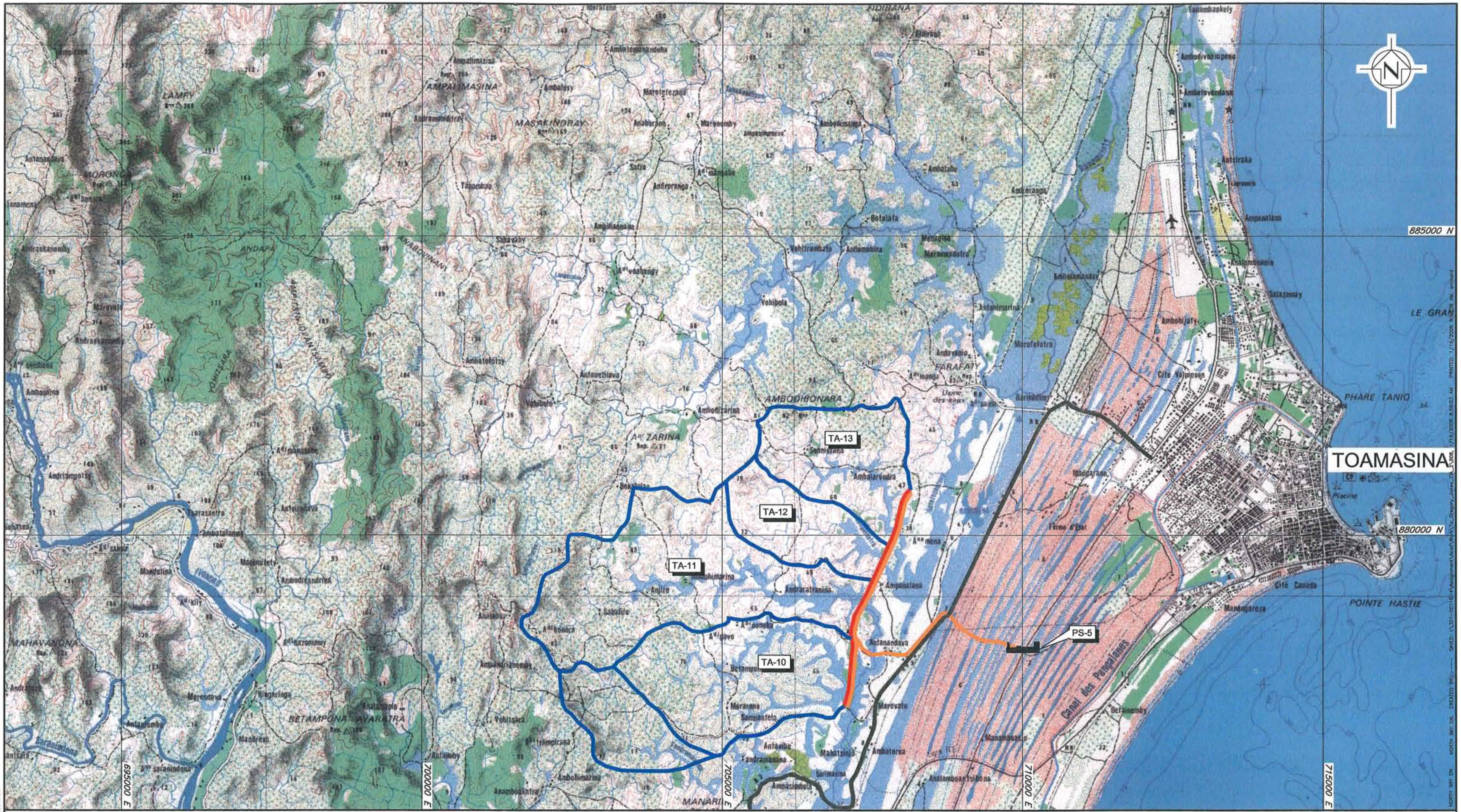
AMBATOVY PROJECT

ALTERNATIVE TAILINGS FACILITY LOCATIONS IN THE BRICKAVILLE AREA

Knight Piésold CONSULTING

P/A NO.	REF. NO.	REV.
NB301-00116/4	–	–

FIGURE 1–1



LEGEND:

- Water
- RN–2
- Potential Ore Slurry Delivery Pipeline Route
- TA-11 — Potential Tailings Area Basin Watershed
- Possible Embankment Alignment
- PS-5 — Possible Plant Site Location

NOTES:

1. Based on 1:50,000 FTM Topographic Map No. V45.

Scale: 600 0 600 1200 1800 2400 3000 Metres

XREF FILE : Mosaic_1to100000; Site_Reconnaissance

AMBATOVY PROJECT			
ALTERNATIVE TAILINGS FACILITY LOCATION IN THE TOAMASINA AREA			
Knight Piésold CONSULTING	P/A NO. NB301-00116/4	REF. NO. –	REV. –
	FIGURE 1–2		

1.1 SELECTION OF PREFERRED ALTERNATIVE

Three tailings facility locations were selected for further consideration including cost estimates:

- Brickaville location TA-6;
- Toamasina locations TA-10 and 11; and
- Toamasina ring dyke alternative.

As noted above the Toamasina area was selected as the preferred area for the plant, thus the Brickaville location was not considered further. The high cost of the ring dyke alternative and questionable integrity precluded its further consideration. The TA-10 and 11 location was selected for further evaluation, based mainly on capacity considerations.

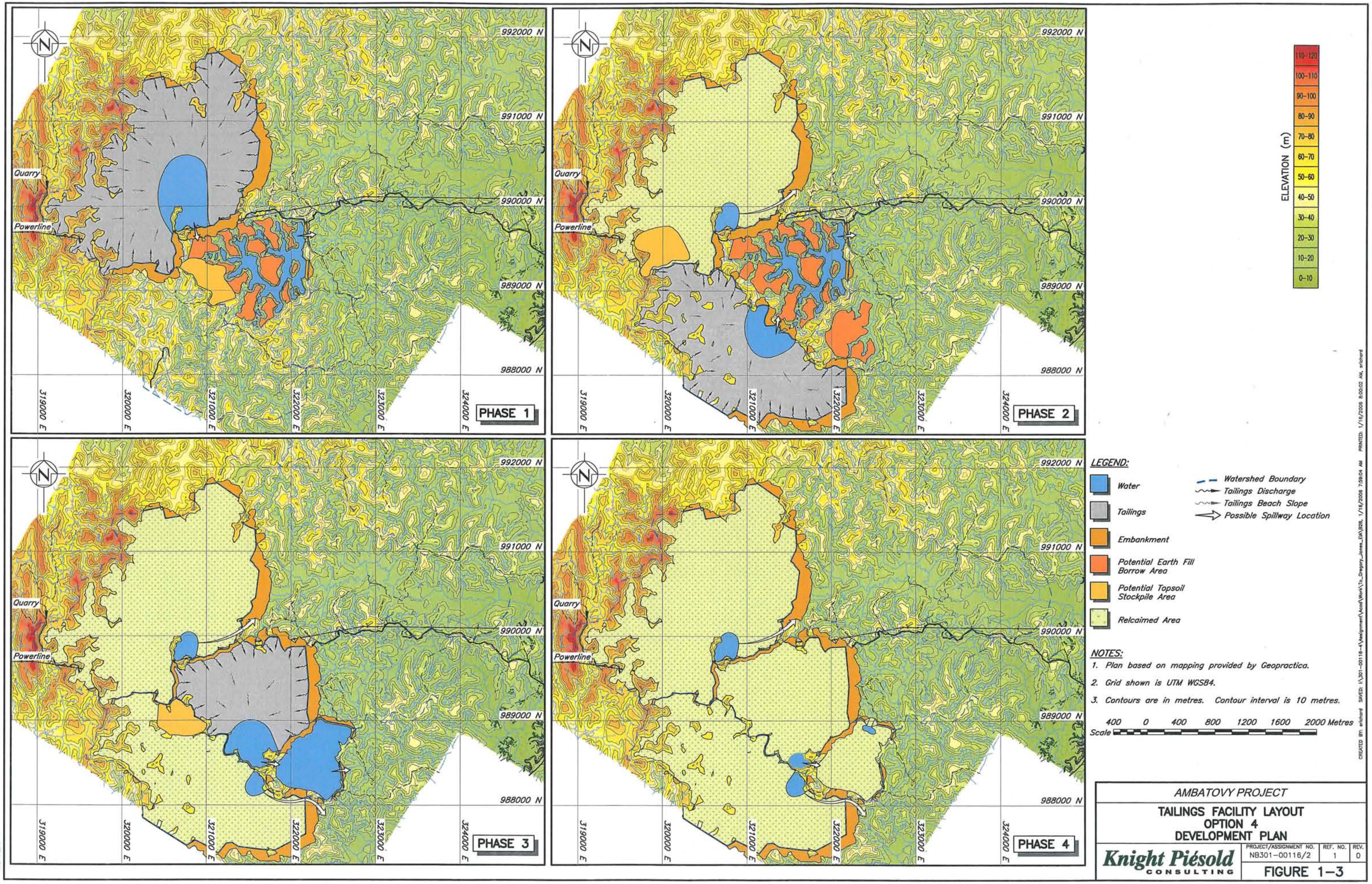
Once a preferred site was selected, a more detailed analysis of design options was completed for the facility in the chosen area.

1.2 DESIGN OPTIONS

The storage efficiency of the recommended site for tailings disposal was noted to be good, minimizing embankment construction and ultimate tailings disposal costs. Several factors were considered in selecting the best development option including socioeconomic conditions in the valleys, geologic conditions, water management criteria and the potential for future reclamation.

Minimizing the tailings footprint and locating the site to minimize effects on people living in the area, were the main goals in developing the preferred tailings option.

The four options considered for development of the TA-10 and 11 valleys are shown in Figure 1-3.



PHASE 1
PHASE 2
PHASE 3
PHASE 4
Quarry
Powerline
992000 N
991000 N
990000 N
989000 N
988000 N
319000 E
320000 E
321000 E
322000 E
323000 E
324000 E
ELEVATION (m)
110-120
100-110
90-100
80-90
70-80
60-70
50-60
40-50
30-40
20-30
10-20
0-10
LEGEND:
Water
Tailings
Embankment
Potential Earth Fill Borrow Area
Potential Topsoil Stockpile Area
Relcaimed Area
Watershed Boundary
Tailings Discharge
Tailings Beach Slope
Possible Spillway Location
NOTES:
1. Plan based on mapping provided by Geopractica.
2. Grid shown is UTM WGS84.
3. Contours are in metres. Contour interval is 10 metres.
400 0 400 800 1200 1600 2000 Metres
Scale
AMBATOVY PROJECT
TAILINGS FACILITY LAYOUT
OPTION 4
DEVELOPMENT PLAN
Knight Piésold
CONSULTING
PROJECT/ASSIGNMENT NO.
NB301-00116/2
REF. NO.
1
REV.
0
FIGURE 1-3

1.3 PREFERRED OPTION

During the site investigation of the TA-10 and 11 valleys in May 2004, the potential socioeconomic impacts from using these two valleys was reviewed in more detail. As a result of these investigations, Option 4 was developed, which minimizes impacts to the downstream or eastern portions of TA-10 and 11 where the valleys are more heavily populated and cultivated. Option 4 is similar to Option 3 for the initial phase but different in later years. To minimize social impacts in the eastern or downstream portions of TA-10 and 11, the upper part of a valley west and south of TA-10 was chosen for Phase 2 tailings deposition while the western portion of TA-10 was selected for a water basin (Figure 1-3). During Phase 3, tailings would be placed in the west portion of TA-10 with a new water basin being placed to the east within TA-10. A more detailed description of each phase is provided in the next section.

In terms of economics, Knight Piésold has indicated that Option 1 has the lowest estimated construction cost, followed by Option 2, 3, and lastly, Option 4. However, it has been realized that reduced construction cost does not compensate for the upfront socioeconomic impact and the cost of relocation of the population within the valleys. There is a relatively large population in the eastern end of the valleys, and this would have an adverse effect on project cost and schedule, as well as a high socioeconomic impact.

The first phase of Option 3 and Option 4 would be built in an area of lower population density than Option 1. However, the higher population density area would eventually be developed. Option 4 does not use the lower elevation areas of the valleys and, therefore, avoids the areas of highest population density. For this reason, Option 4 was selected as the preferred option.

2 PROJECT DESCRIPTION

The criteria for tailings facility site selection were based on factors outlined in the previous section and the total required storage capacity to satisfy both solids storage and water management objectives. Based on preliminary water balance analyses, the required operational water storage is estimated to be 7 to 8 million cubic metres (Mm^3) while the environmental design storm (EDS) storage allowance is estimated to be 6 Mm^3. Therefore a total required storage capacity of about 200 Mm^3 for tailings, water storage and freeboard has been used for preliminary design.

2.1 DESIGN STANDARDS

The design basis and criteria for the tailings facility are based on International Standards for the design of dams. In particular, all aspects of the 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), in particular Tailings Dams and Seismicity - Review and Recommendations (ICOLD 1995); and
- 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…”.

2.2 GENERAL DESIGN CRITERIA

The following general project design criteria have been used for the design of the tailings facility:

- The preliminary design requirements are based on an annual production of 60,000 tons of product from the mine.
- The operating life of the project is 27 years.
- The estimated tailings flow is approximately 20,500 dry tonnes per day at 38% solids.

- The specific gravity of the tailings particles is 3.5, while the estimated average in-situ dry density upon settling in the tailings facility is 1.0 t/m^3.
- Sufficient operational water storage capacity must be provided within the tailings facility to allow adequate storage time to permit solids settlement. Rainfall generally occurs all year and the peak rainfall season is during the summer months, between November to March. Maximum evaporation also occurs during the summer months. The reported average precipitation for Toamasina is 3,300 mm/yr and the average pan evaporation is 800 mm/yr in the area. Therefore there is a substantial water surplus.
- Construction of a water return pond to store water before it is removed from the facility. The purpose of this basin is to minimize the length of time supernatant water remains on top of the tailings.
- The excess water (runoff and supernatant) under normal operating conditions will be discharged to the ocean with a small return flow to the process plant. The Excess Water removal rate will be set to keep the water levels in the tailings facility within the normal operating range, except under extreme conditions.
- In order to minimize the discharge of water directly to the environment, the tailings facility will also be capable of temporarily storing a 1 in 50 year storm (environmental design storm, EDS) above the maximum normal operating level (MNOL). Under this scenario, the chance of a discharge directly to the environment in a 27-year operating period will be about 50%.
- Based on the CDA consequence rating the tailings facility will need to be able to safely pass an inflow design flood (IDF) resulting from the probable maximum precipitation (PMP). Therefore, sufficient freeboard (wet freeboard) must be provided above the EDS level to pass the PMP through a suitably sized overflow spillway. In addition, freeboard above the IDF maximum flood level (dry freeboard) will need to be provided to handle wave run-up during a cyclone event.

2.3 PHASED DEVELOPMENT

A three-phase construction plan of Option 4 is described below followed by a reclamation plan shown in Section 1 of this Volume, Figure 1-3.

Phase 1

Phase 1 will involve discharging tailings within the west end or upstream extents of the TA-11 valley. The water basin will be located within the west portion of TA-10 for years 1 to 14. Phase 1 will require the construction of embankments across the TA-11 valley and a service road around the north and south perimeter for the placing of the tailings distribution piping to the western end. The embankment would ultimately be built to an elevation of 80 m with the maximum supernatant pond level below an elevation of 76 m. The northern and southern perimeter service roads will be built to approximately an elevation of 75 to 85 masl.

The initial return water pond will be sited to the south east of this area, within the upstream portion of the TA-10 valley. The initial return water pond will store a total volume of approximately 7 Mm^3 and the embankments for this dam will be built to an elevation of 40 masl.

Phase 2

Phase 2 will involve the development of a tailings basin within the valley immediately south of TA-10 (south valley). Embankments will be constructed across the east end of the south valley and along the ridge to the south. The initial return water pond within the west portion of TA-10 would continue to be used during Phase 2. In addition to the embankments, a new service road will need to be constructed along the south and west sides of the south valley for tailings distribution piping. The Phase 2 tailings basin will be developed to an elevation of approximately 65 m to accommodate tailings for six years (years 15 to 21).

Phase 3

Phase 3 will involve construction of a new water basin east of the Phase 1 and 2 water basin within TA-10 so that tailings can be placed within the west portion of TA-10. Tailings will be discharged predominately from the west and north to ensure all runoff and supernatant reports to the final return water pond to the southeast. The Phase 3 tailings basin will be developed to an elevation of approximately 60 m to accommodate the final six years of operations from (years 21 to 27).

Final Reclamation

The final reclaimed facility will be vegetated and have several small sedimentation ponds.

2.4 LAND ACQUISITION

Long term lease applications have been submitted as follows:

AFF – 20897 TAM	03/11/04	874 ha
AFF – 20980 TAM	15/12/04	235 ha
AFF – 20981 TAM	15/12/04	8 ha
AFF	19/07/05	683 ha
Total:		1,800 ha

Detailed on-site surveys have been carried out to identify plot owners and plot areas, and inventory the constructions and crops on each plot. A total of 154 plots are located in the area, of which 12 are provisionally titled, 1 has a definitive title, 26 have pending title applications and 78 are plots on state land. All aspects addressing potentially affected persons including the area and people identified in the neighbouring areas to relocate the affected population are addressed in the Resettlement Action Plan.

2.5 EARTHWORKS DESIGN

2.5.1 Construction Materials

Construction of tailings embankments, access roads, upgrade of the spine road between TA-10 and TA-11, and the return water dams will require the borrowing of material sourced predominantly from the local area. Material will be borrowed from within the tailings basin footprints as much as possible to minimize disturbance outside the tailings facility limits.

Sand for filter drains will be sourced either from the alluvial plain near the plant or the sand-winning operation just outside of Toamasina on the road north. Coarser granular materials for filters, road topping and rip-rap for erosion protection will be quarried from dolerite dykes that are found in the area.

2.5.2 Embankment Cross Section

The proposed embankment cross section for both the tailings and water basins comprised of a homogeneous structure consisting of local weathered gneiss (clayey silt fill) and a sand chimney filter and blankets as required for internal drainage and stability. Upstream slope erosion protection will be provided by placement of rip-rap while downstream slope stability between raises will be provided by placement of erosion-control turf matting on rip-rap.

Stability analyses of generalized embankment cross sections indicates that slopes of 2H:1V for initial starter embankments will be adequate while a 3H:1V downstream slope will be required for later years to maintain adequate stability at higher heights. Downstream construction will be used for the initial starter dam with centreline construction for ongoing raises to tailings embankments to minimize ongoing fill requirements.

2.6 TAILINGS DELIVERY AND DEPOSITION

2.6.1 Tailings Delivery System

The tailings delivery pipeline will be 600 mm in diameter (unlined steel) and will be routed from the tailings pumps in the plant site, exiting the boundary fence in a southerly direction. At this point the pipe will be buried and will run west along the plant fence, under the Route Nationale (RN) 2. It follows the RN2 for about 2,000 m and then turns west through the valley into the tailings dam area up along the Phase 1/2 water basin to the bifurcation point on the east side. The main distribution piping will run on the impoundment walls.

The slurry pumping system at the process plant will include two trains (one running and one standby) of five centrifugal pumps in series to cater for discharging slurry at the anticipated maximum dam wall elevation.

2.6.2 Tailings Distribution System

The tailings distribution system will include spigot pipes around the complete perimeter of each of the tailings basins. The placement of spigot pipes across the upstream crest of embankments as well as around the perimeter of the basins will allow for controlled discharge of tailings slurry to maximize storage potential and densities. A distribution pipeline will generally be routed around both sides of each tailings basin. This will require that a flow control assembly be placed at the bifurcation point to allow tailings flows to be directed along either distribution pipe or to a shorter length emergency discharge pipe.

A service road approximately 10 m wide will be provided for inspection and maintenance of the tailings distribution pipeline around the catchment perimeter. Some of this road work will be performed during the perimeter embankment construction.

2.7 WATER MANAGEMENT DESIGN

2.7.1 Operational Flows

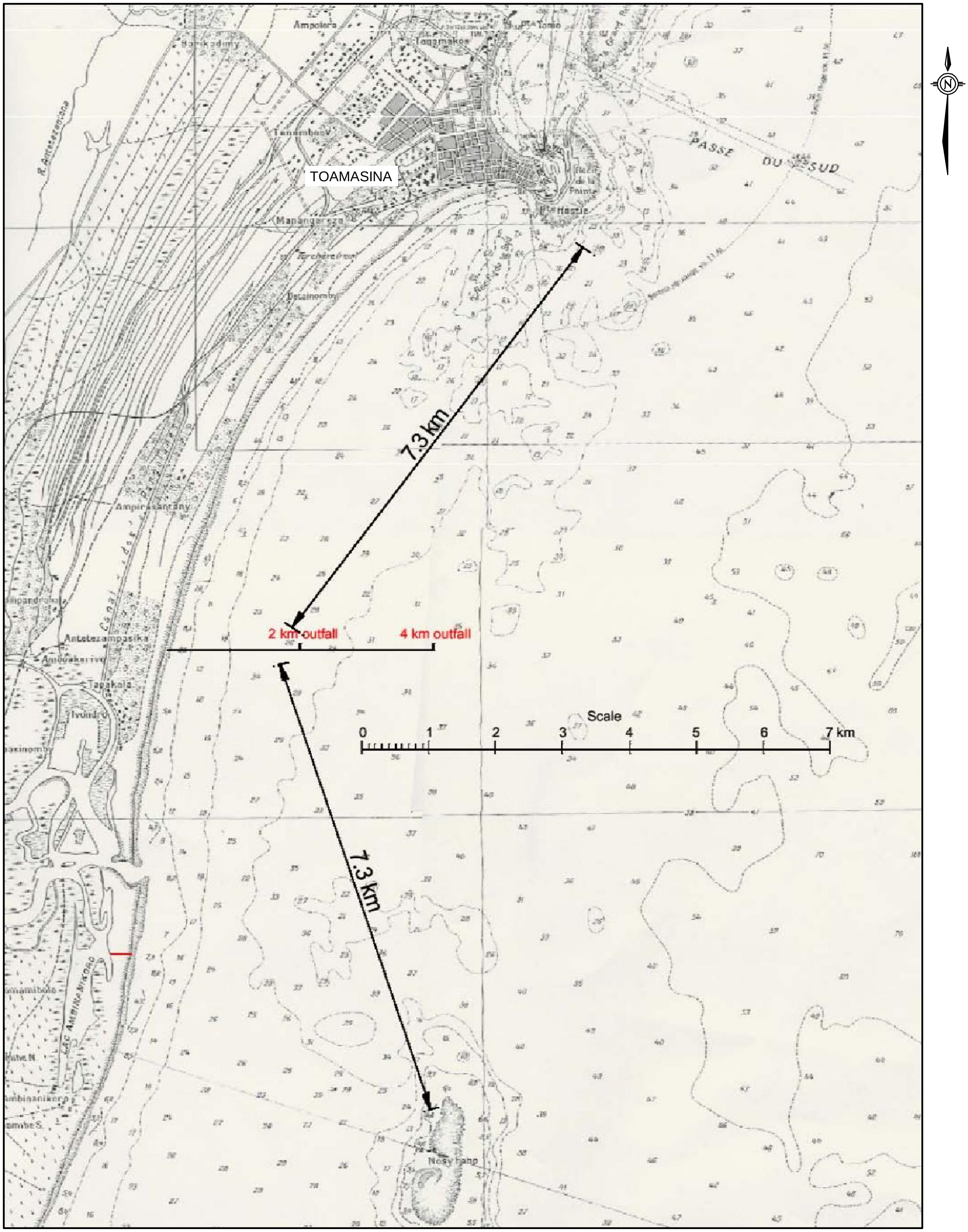
A water balance analysis was completed to estimate operating water storage requirements and excess water removal pumping rates for the return water back to the plant. Based on the water balance, a total operating water storage requirement of 4 Mm^3 has been estimated for the water basin to satisfy operational water storage requirements for each phase. Such storage provision will allow excess runoff from wetter months to be temporarily stored until it can be removed from the tailings facility during dryer months. Water balance results for average precipitation conditions indicate that the average return water pumping rate will be about 2,500 m^3/hr. To provide adequate excess water removal capacity for more extreme periods, the return water system maximum design flow has been estimated at 4,000 m^3/hr for all phases.

Gravity decant weirs with stoplogs for controlling water levels will be used to transfer water from the tailings basin to the water basin. This will require the tailings basin to be partially flooded in the first few months of operations for each phase to allow flow to the water basin by gravity. A barge type pump arrangement will be used for excess water removal and return to the plant from the water basin. The barge system will be relocated to the final return water return pond at the start of Phase 3.

A network of groundwater collection wells will be established immediately downgradient of the constructed embankments. These wells will be designed to intercept seepage from the tailings facility in order to prevent downstream surface water quality impacts. Water from these wells will be pumped to the water basin and managed with the supernatant and storm water collected in the tailings facility.

2.7.2 Effluent Treatment

The tailings area will offer an opportunity for the solids to settle and consolidate. Before pumping to the tailings pond, the water is neutralized to pH 8. At this pH most of the metals will be precipitated as solids and immobilized in the tailings facility. Supernatant water, which will include rainwater, will be pumped from the tailings facility 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 outfall pipeline. This effluent will be pumped out to sea at a maximum design flow of 4,000 m^3 per hour. The length of the section of pipeline out to sea may be about 1 km where water depth is approximately 20 m (Figure 2.1).



PROJET

AMBATOVY PROJECT

TITRE

LOCATION OF OUTFALL PIPELINE SOUTH OF TOAMASINA

Golder Associates
Calgary, Alberta

PROJET	03-1322-172.5323		FILE No. Outfall Location
PROJETE PAR	GJ	28/11/05	ECHELLE TELLE QU'ILLUSTREE REV. 0
DESSIN CAD	SWD	28/11/05	
VERIFIE PAR	GJ	24/01/06	FIGURE: 2-1
REVISE PAR	DM	24/01/06	

R:\CAD\2003\1322\03-1322-172\5300\5323\Fig 2.-1 Outfall Location South of Toamasina.dwg Jan 24, 2006 - 4:11pm

The marine outfall will be assembled on land, then floated out to sea, flooded and sunk onto the sea bottom. In developing the design of the outfall, the designer will need to decide whether the pipeline is to be trenched and buried over its full length, or whether the seaward portion can be exposed on the seabed. In the former case, burial depth, together with any armouring provided over the pipe, should be designed for stability against scour and liquefaction under the design loading. In the latter case the pipeline will require sufficient weight to remain stable under the maximum wave and current loading.

Storm Water Management

The tailings facility has been designed to contain a 1 in 50 year storm above the maximum normal operating level (MNOL). 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 available), it is estimated that 3.0 Mm^3 of storage will be required in the water basin above the MNOL. The decant weirs will have capacity to transfer the water quite quickly to minimize the length of time the tailings basin is flooded. Based on the proposed excess water removal rate of 4,000 m^3/hr it is estimated that it will take up to three months to return the water levels in the tailings basin to normal operating range within the water basin should a 1 in 50 year event occur.

To handle flows in excess of a 1 in 50 year storm, an overflow spillway system will be constructed to pass the inflow design flood from the tailings basins to the water return pond and then to the environment. The overflow spillways will consist of rip-rap and gabion-lined channels up to 200 m wide so that the probable maximum flood can be passed with 1 m or less of head. The final discharge from the water basin will be into the downstream portion of the TA-10 valley. Analyses of downstream areas that could be impacted by the spillway discharge have been conducted to determine required mitigations.

2.8 OPERATION OF THE TAILINGS FACILITY

2.8.1 Embankment Raising

Ongoing raising of the tailings embankments will be required for the duration of operations. Most of the earthworks will need to be completed within the dryer period of the year when conditions are suitable for fill placement operations. Generally, this will involve an annual construction cycle in the second half of each year with some minor items being addressed over the rest of the year. In addition to embankment raising earthworks, new decant weirs will be constructed each year and overflow spillways will be expanded or new spillways will be constructed as required.

2.8.2 Tailings Deposition Plan

The tailings deposition plan will be based on the following general objectives:

- Rotate discharge of tailings around the perimeter of each basin on a regular basis. This will deposit tailings in relatively thin layers and will promote drainage of supernatant and air drying as much as possible to maximize density and strengths.
- Discharge tailings from the embankments and perimeter to locate the supernatant pond towards the discharge side of the facility to maintain gravity drainage and minimize seepage through the walls.
- Discharge tailings such that the base of the basin is covered within the initial operating period to minimize seepage through the foundation.

Phase 1

Tailings will initially be deposited into the Phase 1 tailings basin from the east and north sides to push the initial return water pond to the southwest and move it away from the tailings embankment and towards the spillway to the water basin. This will require that the north service road is constructed for year 1 operations. Following year 1, the south service road will be constructed so that additional tailings can be deposited from the west. This will centralize the supernatant pond with ongoing tailings deposition from the east and north to maintain gravity drainage to the spillway location. Approximately 117 Mt of tailings will be placed within the Phase 1 tailings basin with tailings elevations as high as 80 m by year 14 of operations.

Phase 2

The Phase 2 tailings basin will be commissioned in year 15 by initially discharging tailings from the east and south. This will push the supernatant pond towards the spillway location along the north side where water will be decanted to the water basin. Ongoing tailings deposition will then be cycled around the west, south and east portions of the Phase 2 tailings basin. This will maintain the supernatant pond against the north central part of the basin for decanting into the water basin. It is anticipated that the Phase 2 tailings basin will be constructed to an elevation of 65 m for storage of 50 Mt of tailings.

Phase 3

The Phase 1 and 2 water basin will be used for tailings storage starting in year 21. This will require a new (final) water basin to be constructed to the east within the TA-10 watershed. Initially, tailings will be discharged into the Phase 3 tailings basin from the west and north. This will push the pond to the southwest to minimize seepage potential to the east. Ongoing tailings deposition will be conducted from the east, north and west to push the supernatant pond to the southeast corner of the Phase 3 tailings basin for decanting into the final water basin. Some additional tailings deposition may also be conducted within the Phase 2 area if required to push the remaining supernatant pond area further east towards the final water basin location. The Phase 3 tailings basin will need to store about 40 Mt of tailings requiring it to be developed to an elevation of 60 m in Year 27 of operations.

3.1 TOPOGRAPHY AND GEOMORPHOLOGY

3.1.1 Introduction

This section presents the Environmental Assessment for the effects of the tailings facility on topography and geomorphology, including unique topographic features, as per the Ambatovy Project (the project) Terms of Reference.

3.1.2 Study Area

The tailings facility Local Study Area (LSA) for topography and geomorphology is the same as the tailings facility terrestrial study area (a sub-area of the Toamasina region study area) presented in Volume A, Figure 7.2-3. It includes the tailings facility, corridor from the tailings facility to Route Nationale (RN) 2, and buffer areas within 500 m of these planned disturbances.

3.1.3 Baseline Summary

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 (metres above sea level) 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 in the valleys along a natural gradient of less than six degrees (10%).

Based on a qualitative analysis of the landscape, the tailings facility LSA is not considered to contain any unique topographic features.

Additional details concerning baseline conditions are provided in Volume I, Section 1.1.

3.1.4 Issue Scoping

The main potential issues relating to topography and geomorphology are:

- initial removal and disturbance of unique or important topographic features important for social or biological reasons; and

- changes in the landscape and underlying geomorphology slope which may represent important issues over the long term to people or the environment.

Depending on the amount of terrain recontouring at the time of reclamation, local changes in topography may have implications for hydrology, hydrogeology, visual effects, growing conditions for flora, habitat for fauna, aquatic habitat and closure planning.

The key question for topography and geomorphology is:

Key Question TG-1 What Effect Will the Tailings Facility Have on Topography and Geomorphology?

Potential impact pathways associated with impacts on topography and geomorphology are presented in Volume H, Appendix 9. During construction and operation phases, topographic and geomorphologic features of the landscape will be disturbed. Slopes and topography will be altered during the construction, operation and closure phases.

3.1.5 Impact Assessment

3.1.5.1 Assessment Methods

Existing topography was studied using literature and topographic maps. The relative uniqueness of topographic features was assessed by comparing the features to be affected by the project with other features in the LSA. The characteristics of pre-project topography was compared qualitatively with topography following development of the tailings facility.

3.1.5.2 Assessment Criteria

The assessment criteria used for topography and geomorphology are presented in Table 3.1-1.

Table 3.1-1 Impact Description Criteria for Topography and Geomorphology

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency
neutral: no change in topography negative: a change in topography that affects function for human or biological services	negligible: no measurable effect on slopes and landscape-level topographic features low: slight changes in slopes or overall topographic layout moderate: locally prominent changes in slopes or overall topographic layout high: regionally prominent changes in slopes or overall topographic layout	local: effect restricted to the LSA regional: effect extends beyond the LSA	short term: <3 years medium term: 3 to 30 years long term: >30 years	reversible or irreversible	low: occurs once medium: occurs intermittently high: occurs continuously

3.1.5.3 Mitigation

During construction, operations and closure, erosion control measures will be applied as described in Volume E, Section 6 to minimize the formation of gulleys and the removal of surface material due to water and wind erosion.

During construction, operations and the beginning of the closure phase, water management systems will be used to catch flows along the base of disturbed features and mitigate siltation in downstream basins. This will be particularly important to mitigate effects on valleys downstream that are productive for rice production and other land uses.

During the operations and closure phases, reclamation will occur. Revegetation will reduce erosion of surface material and will help to maintain slopes and other topographic features. Slopes will be contoured to maintain long-term stability. Closure landforms will be designed such that there will be continuity of landforms and watershed systems between undisturbed land and reclaimed areas.

3.1.5.4 Results

Three valleys will be affected by the project. Over the course of construction and operations, a variety of landscape features including dams, linear access routes, drainage ditches and a flattened surface of the tailings pond will be developed, altering local topography.

Initial embankments for the tailings area will be constructed with slopes of 2H:1V (27 degrees). For on-going raises the downstream slope will be 3H:1V (18 degrees) to maintain stability. The surface of the tailings facility will evolve over time during the operations phase with the development of beaches in each area where tailings are fed into the pond. At the time of reclamation, the tailings pond surface is expected to be relatively flat.

3.1.5.5 Impact Analysis

Residual Impacts

Following mitigation, the residual effects during each project period are summarized in Table 3.1-2.

Table 3.1-2 Potential Effects and Residual Impacts for Topography and Geomorphology

Project Period	Potential Effects	Mitigation	Residual Impacts
construction	changes in the landscape and slopes during short-term construction	erosion control; water management; stable slope engineering	moderate magnitude/short-term modification of tailings facility dams, tailings facility access route and adjacent topography
operations	changes in the landscape and slopes which may represent important issues over the medium term to stakeholders and biodiversity	erosion control; water management; stable slope engineering; progressive reclamation	moderate magnitude / medium-term modification of tailings facility dams, tailings facility surface area and adjacent topography
closure	changes in the landscape and slopes which may represent important issues over the long term to stakeholders and biodiversity	erosion control; water management; stable slope engineering; full reclamation and recontouring of pond surface area	moderate magnitude / long-term modification of tailings facility area

The existing topography of the tailings facility LSA is hilly with relatively steep slopes, except at the eastern end of the tailings facility access corridor, which extends into level terrain. The areas affected by topographic change due to the tailings facility include relatively steep-sided valleys and ridges, and flatter valley bottom areas.

The tailings facility will have a direct impact on the landscape. Generally, impacts will be long-term, because to maintain the integrity of the dam structures, they will be left in place following closure. Construction will occur continuously through the operations phase since embankments will be raised periodically. The magnitude of the changes are considered moderate during construction and operations, with the development of embankments and ponds contained within them. The impact magnitude is moderate during the closure phases, as the development of the flat-topped facility will be a large, locally observable change in the shape of the landscape.

Slopes of tailings facility dam features, both during mining and after reclamation, will fall within the natural range of variation of slopes existing in the area. However, the orientation, regularity and diversity of slopes will change, and on a local basis the topographic changes will be very noticeable, with the potential to affect local biological systems and human use of the land in the long term.

An overall residual impact classification for topography and geomorphology for each phase of the project is presented in Table 3.1-3.

Table 3.1-3 Residual Impact Classification for Topography and Geomorphology

Phase	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key Question TG-1	**What Effect Will the Tailings Facility Have on Topography and Geomorphology?**						
construction/ operations	negative	moderate	local	long-term	no	medium	moderate
closure	negative	moderate	local	long-term	no	low	moderate

Prediction Confidence

The baseline status of topography in the LSA is well understood. The eventual form of the landscape following reclamation has also been established. Impact ratings are dependent on the success of the mitigations proposed, including erosion control and slope stability engineering. Overall, the prediction confidence for this assessment is considered high.

Monitoring

No monitoring is proposed specifically for topography and geomorphology. Monitoring of the effectiveness of erosion control measures, slope stability, and reclamation success are described in Volume E, Section 6.

3.1.6 Conclusions

The tailings facility will have a negligible effect on topography during the construction phase, low effects on topography during the operations phase, and a moderate effect during the closure phase because, even with reclamation, the landscape will remain in an altered state for the long term after closure.

Implications of changes to topography and geomorphology for other disciplines are addressed in other sections of this report.

3.2 GEOLOGY AND GEOCHEMISTRY

3.2.1 Introduction

This section discusses impacts on geology and geochemistry for the tailings facility of the Ambatovy Project (the project). Changes in geochemistry are not considered as direct residual impacts in themselves, but are rather used in the water quality Environmental Assessment (EA).

The study area for geology and geochemistry is the same as the soils study area shown in Volume A, Section 7, Figure 7.2-3.

3.2.2 Baseline Summary

3.2.2.1 Geology

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. The geology of the area is extensively weathered. Highly weathered, sandy silt to silty sand saprolite material is present to depths of between 10 and 30 m. 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.

3.2.2.2 Geochemistry

A geochemical characterization program was performed on several samples of neutralized tailings from Dynatec's pilot plant processing of Ambatovy ore. Details are provided in Volume I, Appendix 2.1. 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 tailings when exposed to the environment; and

- the potential of these materials to impact surface water and groundwater quality by leaching chemical constituents.

The tailings geochemical characterization program conducted by Dynatec included the following:

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

The geochemical testing program resulted in the following findings.

The tailings samples included in Dynatec's geochemical characterization program are considered to be representative of expected operational processing conditions. The QA/QC procedures and standards followed by SGS Lakefield Research and Dynatec Technology Services are described in Volume I, Section 2.1. However, it is not possible to determine the precision and accuracy of the analytical results generated by these investigations.

The chemical compositions of the two tailings samples tested are consistent with their mineralogical make-up, comprising principally hematite and gypsum [$CaSO_4\,2H_2O$] with lesser amounts of hydronium alunite [$(H_3O)Al_3(SO_4)_2(OH)_6$], silica and unleached chromite [$FeCr_2O_4$]. The compositions are typical of residues produced by pressure acid leaching of laterites.

Based on the acid-base accounting results, the two tailings samples tested are classified as being non-acid-generating with Neutralization Potential Ratio (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 greater than 5.5.

Despite having been generated by different methods, the chemical compositions of the six entrained tailings solutions included in the geochemical characterization program 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.

Sequential leach testing of two tailings samples demonstrates that values for pH vary only slightly over the three leaches. 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.

Exceedances of Malagasy and/or World Bank open pit mining effluent standards (Volume I, Appendix 2.1) are observed for manganese, sulphate and conductivity in all entrained tailings solutions. Since sulphate is the dominant dissolved constituent and occurs at significant concentrations, elevated values for conductivity are observed as well. For the leachates from the sequential testing, the exceedances also are limited to manganese, sulphate and conductivity. This is in contrast to exceedances observed for the mine rock and ore, which were generally related to chromium, nickel and iron (Volume B, Section 3.2).

Due to the limited ability of static leach tests to simulate ambient site conditions, the presence of exceedances does not imply that such exceedances will indeed be observed on-site. For instance, the attenuation potential of certain lithologies will result in reduced concentrations relative to those observed during the leach testing. Monitoring of on-site groundwater and surface water quality will assist in further identifying the potential for metal leaching under operating and closure conditions.

3.2.3 Impact Assessment

3.2.3.1 Assessment Methods

Geology

There are no valid impact pathways for geology at the tailings facility. No existing geologic resources will be removed or sterilized by the development of this facility. The only potential loss is that of aggregates (granular resources) which are covered by tailings. However, the economic value of such granular deposits are low, and other potential sources are available in the region, this aspect is further addressed in the Socioeconomics Section (Volume E, Section 5.1). No impact assessment is required for the tailings facility for geology.

Geochemistry

There is one valid impact pathway for geochemistry: the metal leaching from the tailings may result in effects on water quality. The linkage diagram for geochemistry is provided in Volume H, Appendix 9.

Derivation of Input Water Qualities for Water Quality Model

A Water Quality Model is used to predict potential water quality impacts to the receiving environment (Volume E, Section 3.10). The model consists of several catchments in which the tailings facility contributes runoff. This section describes the derivation of the water quality from the tailings facility used as an input to the Water Quality Model.

In collaboration with technical staff from Dynatec, analytical results from six entrained tailings water samples were reviewed and results selected that best represented the proposed operational conditions. A dilution factor of 50% was applied to account for dilution by rain water.

Use of the entrained water results requires the important assumption that they are representative of tailings porewater under ambient conditions.

Single-stage tests are not capable of simulating transient behavior such as sulphide oxidation. Although the latter is not of concern for the Ambatovy tailings due to a general absence of reactive sulphides, sequential leach testing of tailings identified concentration trends over time that were not captured by the entrained water quality which formed the basis for the derivation of input water qualities.

For the tailings, only six entrained water samples were analyzed. Due to this small sample set, compositional heterogeneity due to variability in slurry composition and processing methodology was not accounted for. However, the samples represented a large composite of material from testing programs.

3.2.4 Conclusions

Geochemistry impacts are predicted to occur due to the project. These effects are not classified as residual impacts in themselves, but have a direct effect on water quality and are therefore used in the water quality impact analysis (Volume E, Section 3.10).

3.3 SOILS

3.3.1 Introduction and Study Area

This section presents the Environmental Assessment for the effects of the tailings facility on soils, as per the Ambatovy Project (the project) Terms of Reference.

The tailings study area for soils is the tailings project footprint study area presented in Volume A, Section 7, Figure 7.2-3. It includes all the tailings facility direct disturbance areas.

3.3.2 Baseline Summary

3.3.2.1 Regional Overview

Inland around the tailings facility, the geology consists of continental clayey-sandy sandstone with migmatite (gneiss) at the surface. This is in contrast to the geology near the plant site which consists of sandy marine sedimentary materials. 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.).

The coastal area near Toamasina has a warm and humid climate with an average annual rainfall of approximately 3,300 mm and an average temperature of 24°C (Kilian 1968; see also Volume I, Appendix 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).

3.3.2.2 Tailings Soils

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. Although nutrient poor, these soils are suitable for rice paddy production, especially when nutrient deficiencies are addressed through fertilization.

Additional details concerning baseline conditions are provided in Volume I, Appendix 3.1.

3.3.3 Impact Assesssment

3.3.3.1 Issue Scoping

The list of issues from the Terms of Reference (Volume H, Appendix 1) and the public consultation program (Volume A, Section 6) were reviewed to focus the soil assessment on key issues and group the issues into common themes.

As part of this process, an interaction matrix was used to evaluate all possible tailings facilities with soil resources (Table 3.3-1). The interactions were rated to highlight the key issues and to help focus the assessment. Only those activities rated moderate or high were analyzed in detail in the assessment. The main potential issues relating to soils are:

- soil removal and disturbance;
- soil erosion;
- loss of soil nutrients;
- soil compaction;
- soil contamination; and
- reclamation.

The key question for soils is:

Key Question ST-1 What Effect Will the Tailings Facility Have on Soils?

A linkage diagram for potential impact pathways is provided in Volume H, Appendix 9. Table 3.3-1 presents the impact of mine activities with soil resources, focusing on key issues.

Table 3.3-1 Project Interaction Matrix

Project Activities or Facilities	Soil[a]	Issue	Comments
pre-construction phase			
geotechnical drilling	N	increased short-term soil erosion risk on slopes >10%	short-term issue
construction and operation phase			
vegetation clearing	H	wind and water erosion; soil compaction from equipment	water erosion risk will be high until exposed areas revegetated
topsoil removal	M to H	wind and water erosion risk increases, loss of soil quality (nutrient loss, soil compaction)	impact depends on length of time soil exposed
tailings dike construction	M to H	wind and water erosion; soil compaction from equipment	impact depends on length of time soil exposed
tailings basin construction	N	no major issues	some topsoil may be salvaged prior to tailings basin construction
reclamation and closure phase			
removal of equipment	P	removal of contamination source	positive effect
site remediation	P	remediation of any contamination	positive effect
reclamation	P	reclamation of disturbed areas	positive effect

[a] Interaction Ratings: N - Negligible; L - Low; M - Moderate; H - High; and P - Positive.

Many of these issues are inter-related. For example soil removal and disturbance is related to loss of soil nutrients. Only those activities rated moderate or high were analyzed in detail in the assessment.

Impact Pathways

Key Question ST-1 analyzes the effects associated with construction, operations and reclamation of the tailings facility on the loss or alteration of soil within the Local Study Area (LSA).

Activities resulting in the direct loss or alteration of soil in the tailings area include site clearing and surface disturbance to permit tailings dike and basin construction and operation. Area preparation for facility construction will involve removing soil cover. Some topsoil may be salvaged for future reclamation operations. While the tailings dike will be progressively reclaimed, tropical soil reclamation methods are still in development.

Tailings facility construction will result in vegetation removal, thereby exposing the soil and increasing the probability for erosion.

The potential loss of soil structure from soil compaction can affect vegetation growth, especially root development, aeration and drainage. Tailings dike construction will involve equipment traffic and activity on soils, with potential compaction.

Spills and leaks during operation can result in the alteration of soil chemistry and physical properties, which in turn can affect vegetation, surface water and groundwater quality.

While topsoil will be salvaged before tailings construction, the loss of nutrients may occur.

Assessment Methods

Soil types directly affected by the tailings were quantified by Geographic Information System (GIS) analysis using the following process:

- the GIS quantified areas of vegetation types to be disturbed within the tailings footprint and this information was used to rate the existing erosion risk of soils; and
- impact ratings were determined based on the net permanent loss of soils during the construction and operations phase, the overall change in area of soils following reclamation and closure, and a qualitative assessment of potential changes in soil erosion risk following reclamation and closure.

3.3.3.2 Assessment Criteria

The criteria used to rate soil residual impacts are outlined in Table 3.3-2.

Table 3.3-2 Assessment Criteria for Soils

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency
positive, **negative** or **neutral** for the measurement endpoints	**negligible**: no measurable effect (<1%) **low**: <10% **moderate**: 10 to 20% **high**: >20%	**local**: effect restricted to the LSA **regional**: effect extends beyond the LSA into the region **beyond regional**: effect extends beyond the region	**short-term**: <3 years **medium-term**: 3 to 30 years **long-term**: >30 years	**reversible** or **irreversible**	**low**: occurs once **medium**: occurs intermittently **high**: occurs continuously

3.3.3.3 Mitigation

Soil Erosion

Soil erosion is the displacement of soil by wind or water action. The potential amount of water erosion expected on land may be calculated by the Universal Soil Loss Equation (Wischmeier and Smith 1961; Gee et al. 1976). Details are provided in Volume B, Section 3.3.

The soil erodibility factor (K) is affected by organic matter content and texture. Soils high in silt and very fine sand are more susceptible to water erosion than other soils. Geotechnical testing suggests that the tailings area will have a high erosion potential due to the fine-textured surficial soils.

Wind and water erosion risk in the LSA is low when there is a vegetative cover. During disturbance, the risk of wind and water erosion will increase. The risk of wind erosion depends on soil texture, moisture and organic matter content, with sandy soils having a higher risk. Water erosion risk increases where slopes exceed 10% and fine-textured subsoils underlay coarse-textured soils. The preliminary tailings plan outlines that tailings pit slopes will be greater than 30% (Volume E, Section 2).

To prevent soil erosion and potential sedimentation from occurring during construction, soil exposure must be minimized and surface runoff controlled, especially during wet weather and in areas close to watercourses.

The following general mitigations will be used to prevent water erosion:

- Salvage some topsoil where feasible and store away from areas of potential erosion.
- Construct temporary cross ditches to redirect surface runoff.
- Construct temporary berms of logs, construction timbers, sandbags or other material as appropriate and available.
- Construct berms with overburden in areas where topsoil has been stripped.
- Construct tailings roads so natural drainage patterns are not impeded and in a manner that runoff to road ditches enters natural drainage systems or contoured containment areas.
- Use temporary erosion control measures such as mulches, mats, netting and/or straw crimping to control erosion until a protective vegetative cover is established. This is especially important for dam walls that will be progressively heightened with more soil, delaying re-vegetation.
- Apply tackifiers where necessary to stabilize soils and use hydroseeders for seeding on steep slopes.
- Promptly seed exposed areas and topsoil stockpiles with a self-sustaining, erosion-controlling seed mix appropriate to the region. It is suggested that Vetiver grass (*Vetiveria zizanioides*) be planted in strips parallel to slopes for testing (NRC 1993) (Volume B, Section 6). Other species can then be planted between the strips of Vetiver.

Loss of Soil Nutrients

Tropical soils are very low in nutrients, with low pH, low phosphorus availability and possible aluminum and manganese toxicity. Nutrient availability is closely tied with soil organic matter content. These characteristics were discussed in Volume B, Section 3.3.

Mitigations to restore soil nutrients in reclaimed tailings soils include:

- Incorporation of organic matter in the surface layer of the reclaimed soil profile including direct topsoil salvage and replacement, placement of composted organic material, mulching and “green manuring”.
- Replacing deficient nutrients with fertilizer amendments.
- Applying liming agents such as calcium and magnesium carbonates to increase soil pH and reduce metal toxicities (Ludwig et al. 2000).

Sustainability of soil nutrients in disturbed soil has been identified as a potential issue in the tropics and will be a major issue in reclaiming the tailings area. It is important to ensure that organic matter is reincorporated during reclamation since the organic matter has an important controlling function on soil fertility (see Volume E, Section 6).

Compaction

Soil compaction is most severe under moist conditions, high loads and areas of repeated traffic use. The effects of soil compaction were discussed in Volume B, Section 3.3.

Mitigation that will be implemented to prevent and alleviate compaction includes the following:

- cultivate compacted soil before revegetation; and
- use deep-rooted vegetation to loosen the compaction.

As discussed in Volume E (Section 6), reclamation of the tailings facility also includes a main challenge of the time required for the material to harden.

Soil Contamination

General mitigations to prevent soil contamination will include the following:

- tailings equipment will be designed with collection systems to minimize loss of containment; and
- cleaning up all spills and leaks promptly.

3.3.3.4 Results

A total of 1,268 ha of soils will be disturbed by the tailings over the life of the project (Table 3.3-3). The majority of disturbed soils will have an existing moderate to high erosion risk (1,185 ha, 93 % of total) as they are under Tavy land use. The remaining soils will have a low existing erosion risk as they have a land use of agroforestry, rice paddies, disturbance and wetlands (83 ha, 7% of total). Before constructing the tailings dikes and basin, sufficient topsoil and subsoil will be salvaged to allow reclamation of the dyke slopes. Therefore, there will be a loss of 1,268 ha of soils during tailings operation (Table 3.3-3). When reclamation is completed following closure, there will a net deficit of soils, due to burial of much existing soil under tailings, which will be mitigated through reclamation of soil material at the surface of the tailings pond areas. A research-based reclamation trials program will be initiated to adequately address the optimal reclamation techniques, given the nature of the tailings material.

Table 3.3-3 Disturbance of Soil Types in the Tailings Area

Soil Erosion Risk	Land Use Types	Area (ha)	Percent of LSA (%)
low	agroforestry, rice paddies, disturbance, wetlands	83	7
moderate to high	tavy	1,185	93
total		**1,268**	**100**

3.3.3.5 Impact Analysis

Residual Impacts

The environmental consequence of the tailings on soils is rated as high during construction and operation, and low following closure (Table 3.3-4).

Tailings construction and operation will result in a gradual disturbance of the area as tailings basin construction progresses. Also, the erosion risk of all soils will increase substantially with the removal of vegetation during dyke construction. Due to the long-term disturbance of soils during construction and operation, the environmental consequence was rated as high.

The environmental consequence was rated as low following closure since natural erosion rates are expected once a stable vegetation cover is established Volume E, Section 6.

Table 3.3-4 Residual Impact Classification for Soils

Phase	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key Question ST-1 What Effect Will the Tailings Facility Have On Soils?							
construction	negative	high	local	long-term	no	low	high
operations	negative	high	local	long-term	no	low	high
closure	negative	low	local	long-term	yes	low	low

3.3.3.6 Prediction Confidence

The soil impact classification relies heavily on the planned reclamation program to establish a productive soil on the tailings material and implement successful erosion control methods. There are uncertainties regarding the reclamation of the tailings, given very high local rainfall. As noted above, there are uncertainties as to how quickly the tailings will harden at closure, to allow re-vegetation. Planned reclamation research will address these issues.

3.3.3.7 Monitoring

The proponent will implement reclamation monitoring programs to ensure mitigation processes are successful and adjust if necessary. The tailings reclamation monitoring plan will consist of:

- ensuring that environmental protection measures are being followed during tailings construction, operations and closure;
- ensuring tailings dike stability;
- measuring vegetation performance; and
- documentation of the monitoring results.

3.3.4 Conclusions

Following mitigation, the tailings will have a high environmental consequence for soils during the construction and operations phase due to the long-term loss of productive land use. There will be a low environmental consequence following closure and reclamation. The main issues are the loss of productive land and the increase in erosion risk of the fine-textured soils on the tailings dikes. The potential impact to soils has implications for vegetation, hydrology and particularly water quality, where there is a likelihood of increased sediment runoff. These issues are addressed in other sections of the EA.

3.4 CLIMATE AND AIR QUALITY

The Environmental Assessment for the effects of the tailings facility on climate and air quality is presented in Volume D, Section 3.3 in combination with the effects of the process plant on air quality in the immediate vicinity of Toamasina.

3.5 NOISE

The Environmental Assessment for the effects of the tailings facility on noise is presented in Volume D, Section 3.4 in combination with the effects of the process plant on noise in the immediate vicinity of Toamasina.

3.6 NATURAL RISKS

3.6.1 Introduction

This section presents the Environmental Assessment for the risks of natural hazards to the public and environment due to the tailings facility, as per the Ambatovy Project (the project) Terms of Reference.

3.6.2 Study Area

The tailings Local Study Area (LSA) is shown in the tailings and plant site area plan presented in Volume A, Figure 7.2-3. This preferred option for tailings storage is in the Toamasina area located about 2 km west of Route National (RN) 2 (between Toamasina and Antananarivo) and about 8 km southwest of Toamasina. The tailings facility covers an area of approximately 9 km^2 and provides tailings storage for the entire 27-year mine life. The area has been deforested and has a cover of secondary vegetation (Volume J, Appendix 1.1).

Natural hazards such as earthquakes can originate from a much larger regional area that was studied as appropriate to determine the potential impacts at the tailings site.

3.6.3 Baseline Summary

The Environmental Assessment is based on a separate study on natural hazards and risk assessment for the tailings facility (Knight Piesold 2005b, which is provided in Volume I, Appendix 6.1). In this reference study, the baseline for the tailings facility setting is described in terms of location, existing land use, topography, geology, climate and seismicity. Potential natural hazards, potential consequences of failure due to natural hazards and risks downstream of the tailings facility were assessed.

Resources downstream of the tailings facility include small human settlements, potable water and agricultural land. 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.

Baseline data for natural hazards included climate data describing hydrological hazards and earthquake data describing seismicity hazards.

3.6.4 Issue Scoping

A natural hazard was defined in the risk assessment (Knight Piesold 2005b) as a naturally occurring event that could lead to potential failure that would impact downstream resources. Three principal natural hazards are identified as seismic, hydrological and geotechnical and the issues associated with each are summarized as follows. All the issues identified from stakeholder consultation were also included in these hazard scenarios (Volume A, Section 6).

Seismic Hazards

Ground motions from an earthquake could trigger:

- A landslide in the watersheds of the tailings ponds 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 off-shore earthquake which could travel inland and damage the embankments.

Hydrological Hazards

Heavy rains or high winds from a large precipitation event or cyclone could trigger:

- A landslide in the watersheds of the tailings or water basins which could cause overtopping or breaching of the embankments.
- Inundation of the tailings or 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 or 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.

Geotechnical Hazards

Unforeseen geotechnical conditions could occur as an isolated event or in concert with a seismic or hydrological event triggering:

- 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/or oversteepening of the embankments that could cause overtopping or breaching of the embankments.

The key question for natural hazards is:

Key Question TG-1 Are the Risks of Natural Hazards to the Public and Environment Increased as a Result of the Tailings Facility?

3.6.5 Impact Assessment

3.6.5.1 Assessment Methods

A risk assessment was completed for natural hazards (Knight Piesold, 2005b) using a relative ranking system. For each of the three identified natural hazards described in Section 3.6.4, all potential hazard scenarios were first identified according to failure mode, associated consequences and planned risk mitigations. The residual risks for all hazard scenarios were then estimated using a relative risk ranking system. Acceptable risks were determined according to international standards to minimize risk to downstream public and environmental resources.

3.6.5.2 Assessment Criteria

The assessment criteria used for the assessment of natural risks are presented in Table 3.6-1. Five categories of risk are defined by likelihood of occurrence and magnitude of consequences. Overall risk is a product of the relative ranking for likelihood and consequence.

Table 3.6-1 Description of Risk Criteria for Mining

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:

1. Ranking Category “Extremely Low” signifies negligible occurrence potential.
2. Details above adapted from Pelletier and Dushnisky (1993) and Davies (1998)

3.6.5.3 Mitigation

Several risk mitigations were identified in the reference report (Knight Piesold, 2005b). 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 downstream public and environmental resources.

Risk mitigations were identified for all potential natural hazard scenarios. Mitigation is discussed in the referenced report under the three principal natural hazards: seismic, hydrologic and geotechnical. These risk mitigations include:

- regular inspections and monitoring of hillslopes;
- completion of maintenance measures;
- embankment freeboard;
- spillway;
- geotechnical testing of tailings, fill and foundation materials;
- slope stability analyses;
- international standards for acceptable safety factors;
- design for earthquake-induced ground motions and deformations;
- installation and monitoring of instrumentation;
- installation and monitoring of drainage structures;
- conservative selection of design storm probable maximum precipitation (PMP) and design wind (200 km/h);
- inundation studies;
- storm routing design; and
- emergency response plan.

3.6.5.4 Results

The results of the risk assessment are summarized from the reference report (Knight Piesold, 2005b). 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 are also mostly rated in the Extremely Low category. Detailed geotechnical investigations will be completed to adequately characterize conditions for a suitable detailed design. Therefore, the probability of a large-scale failure and massive release of tailings and/or supernatant water will be Extremely Low.

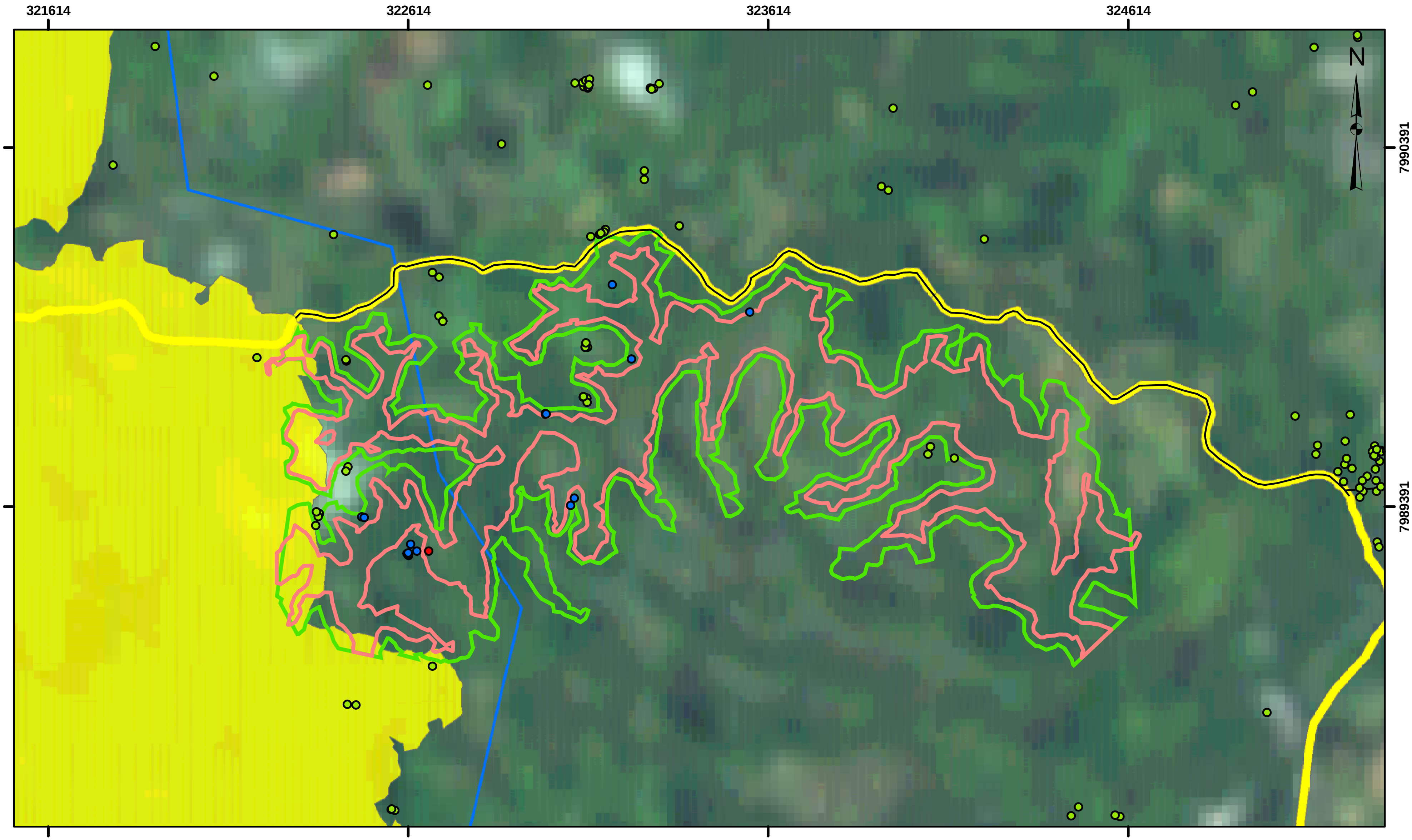
The probability of a small-scale failure leading to embankment damage or a small release is slightly higher due to the possibility of smaller geological features being missed.

For the hydrologic hazard source, most of the failure mode and resulting consequences fall in the Low category with one result in the Moderate category and a few in the Extremely 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 tailings facility 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 (Moderate category). Potential for overtopping and/or breaching of the water pond embankment due to heavy rainfalls has a risk rating in the upper Low category. Therefore, further investigation of these types of risk scenarios was carried out through inundation analyses.

Results from these analyses show that the extent of flooding is relatively similar with or without the tailings facility in place (Figure 3.6-1). Additional household locations may be subject to flooding under the scenario of a one-hour breach of the tailings facility dam, which is the worst-case scenario anticipated in Knight Piesold (2005b). An Emergency Response Plan will be implemented with a trigger mechanism based on high water basin levels in conjunction with predicted precipitation that could lead to discharge through the spillway. Under this scenario, the evacuation plan would require the evacuation of all potentially affected downstream residents until the risk of high spillway flow has passed.

I:\2003\03-1322\03-1322-172\mxd\Natural_Risks\Fig3.6-1_flood.mxd



LEGEND

HOUSE LOCATIONS
- AFFECTED BY BOTH SCENARIOS
- AFFECTED ONLY BY IMPACTED (PROJECT YEAR 27) FLOOD SCENARIO
- NOT AFFECTED BY EITHER FLOOD SCENARIO

- FLOOD LIMIT (PROJECT YEAR 27 SCENARIO)
- PREDEVELOPMENT FLOOD LEVEL
- PROPERTY BOUNDARY
- ROAD
- DISTURBANCE AREA

400 0 400
SCALE 1:15,000 METRES

REFERENCE

Landsat 7 Mosaic Iimage; Captured April/Sept. 2001. Source of Flood Model Results: Knight Piesold (2005b).
Datum: WGS84 Projection: UTM Zone 39S

PROJECT

AMBATOVY PROJECT

TITLE

EXTENT OF ONE HOUR BREACH FLOODING

Golder Associates
Calgary, Alberta

PROJECT No. 03-1322-172			SCALE AS SHOWN	REV. 0
DESIGN	GJ	26 Aug. 2005	**FIGURE: 3.6-1**	
GIS	TN	31 Oct. 2005		
CHECK	GJ	09 Feb. 2006		
REVIEW	DM	09 Feb. 2006		

3.6.5.5 Impact Analysis

Residual Impacts

Following mitigation, the residual risks during all project periods are in the Extremely Low or Low categories and within international standards to minimize risk to downstream public and environmental resources.

Prediction Confidence

The estimation of risk in the reference report (Knight Piesold, 2005b) accounts for the variation in data and prediction confidence as described in Section 3.6.5.4. However, risk ratings are also dependent on the success of the mitigations proposed, including those listed in Sections 3.6.5.3. Overall, the prediction confidence for this assessment is considered medium.

Monitoring

Monitoring programs were summarized in Section 3.6.5.3 for hillslopes, instrumentation and drainage structures.

3.6.5.6 Conclusions

Following mitigation, increased risks of natural hazards to the public and environment as a result of the tailings facility are estimated to be low and within international standards.

3.7 HYDROGEOLOGY

3.7.1 Introduction

This section presents the Environmental Assessment (EA) for the effects of the tailings facility on hydrogeology, as per the Ambatovy Project (the project) Terms of Reference.

3.7.2 Study Areas

The tailings facility is located in the upper valley of three parallel tributaries to the Ambolona River. The Local Study Area (LSA) for hydrogeology is the area included in the numerical model by GCS (Pty) Ltd., as shown on Drawing No. 4 included in Volume I, Appendix 7.2. It includes the area of the proposed tailings facility as well as the three river sub-catchments flowing west to east from the facility to the Ambolona River.

3.7.3 Baseline Summary

3.7.3.1 Introduction

Baseline hydrogeologic conditions in the tailings area were characterized by carrying out a hydrogeological site investigation and completing numerical flow and contaminant transport modeling. Details can be found in Volume I, Appendix 7.1.

3.7.3.2 Methods

GCS (Pty) Ltd. carried out a hydrogeological investigation for the Ambatovy Project tailings facility. The main aims of the hydrogeological investigation were as follows:

- To determine the characteristics of the pre-tailings disposal groundwater regime (i.e. quality and quantity).
- 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).

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 can be used to characterize the hydrogeology of the area. It consisted of the following:

- Data compilation, analysis and verification.
- Conceptualizing the area in terms of the hydrogeology.
- Drilling of 6 monitoring boreholes in and around the proposed tailings dam sites. The locations of the groundwater monitoring boreholes (HG series) are shown on GCS April 2005 Drawing No. 4 in Volume I, Appendix 7.2.
- Measure groundwater levels within the area to obtain groundwater gradients.
- Performing aquifer testing on boreholes to obtain aquifer parameters.
- Obtaining groundwater quality samples.

3.7.3.3 Results

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).
- Inter Weathered and Fractured Zone (partially weathered rock).
- Lower Fractured Zone (unweathered rock).

The Upper Weathered Zone consists mainly of decomposed gneiss and/or dolerite (residual soil). The average thickness of this zone is 13 m. It has a lower hydraulic conductivity compared to the other zones and is therefore not the most important unit in terms of groundwater flow. It contributes, however, to a large part of groundwater storage. This zone can form unconfined to semi-confined aquifers. In most cases, differences in rock weathering characteristics often results in variable permeabilities with depth and thus semi-confined aquifer conditions. Packer testing in this zone indicates a permeability of 0.31 m/day ($4x10^{-4}$ cm/s).

The Inter Weathered and Fractured Zone has double porosity flow characteristics, with fractures contributing to most of the groundwater flow. Fractures are, however, often less open due to weathering, compared to fracturing in the unweathered rock. Fractures are both horizontal and sub-vertical. Both the inter-fracture matrix and the upper weathering contribute to storativity. The average thickness of this zone is around 8 m. It contributes to a large fraction of the regional flow component as follows:

- It has a larger hydraulic conductivity compared to the Upper Weathered Zone.
- It is regionally more persistent compared to the Lower Fractured Zone.
- The vertical hydraulic conductivity between the inter weathered and fracture-zone and lower units is often relatively low, forming a less permeable base.

The permeability of the Inter Weathered and Fractured Zone based on packer testing results is estimated to be 0.99 m/day ($1.1x10^{-3}$ cm/s).

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 ($1.3x10^{-3}$ cm/s) based on packer testing results.

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 samples were taken from boreholes HG1, HG2, HG3, HG5 and HG6 in the vicinity of the proposed Tailings Facility (Drawing No. 4 in Volume I, Appendix 7.2). 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.

Chemical constituents that exceed the World Health Organization (WHO) drinking water standards are highlighted in Table 3.7-1.

Table 3.7-1 Groundwater Quality in the Area of the Proposed Tailings Facility

Constituent	Unit	WHO Drinking Water Guidelines	Borehole HG1	Borehole HG2	Borehole HG3	Borehole HG5	Borehole HG6
pH value @ 190°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	*0-0.02*	<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	*0-0.4*	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

Highlighted values: exceed World Health Organization drinking water guidelines.

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 analysed for 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. Biotitic associated with the gneiss and schist also contains aluminium.

- **Zinc (HG3 & HG5)** - occurs in small amount in almost all igneous rocks such as gneiss.

Based on the sample results, groundwater in the proposed tailings disposal facility area could be subdivided into the following types:

- HG1 - Mg, Ca, Na - HCO_3 dominant water;
- HG2 - Mg, Ca, Na - Cl, HCO_3 dominant water;
- HG3 - Na - HCO_3 dominant water;
- HG5 - Na, Mg (Ca) - HCO_3 dominant water; and
- HG6 - Mg, Ca (Na) - HCO_3 dominant water.

Groundwater use in the vicinity of the proposed tailings facility is mainly via spring/seeps, with only one hand dug well identified within the facility footprint. No motorized or mechanical abstraction boreholes have been identified in the immediate vicinity of the tailings facility.

3.7.4 Issue Scoping

The main potential issues relating to hydrogeology are:

- changes to the groundwater system (flow and chemistry) due to placement of the tailings materials and subsequent seepage into groundwater; and
- effects the changes to the groundwater system may have over the long term to people or the environment.

The Key Questions for the effects on hydrogeology surrounding the tailings facility are:

Key Question HG-1 **What Effect Will the Tailings Facility Have on Groundwater Flows and Consequently Downstream Surface Flows?**

Key Question HG-2 **What Effect Will the Tailings Facility Have on Groundwater Quality?**

The consequent question to Key Question HG-2 is what effect groundwater quality will have on surface water quality. The effect of the tailings facility on surface water quality is addressed in Volume E, Section 3.10.

3.7.5 Impact Assessment

3.7.5.1 Impact Pathway Evaluation

Project activities during construction, operations and closure will result in the following: i) reduced groundwater recharge; and ii) changes in groundwater quality.

During construction there will be little impact on groundwater resource, as disturbance to the landscape primarily involves site clearing and the development of embankments for the tailings and water basins.

During operations as deposition of low permeability tailings progresses, groundwater recharge within the tailings basin(s) will decrease due to decreased infiltration rates. Reduced groundwater contribution to downstream surface water reaches may occur. In addition, the seepage from the tailings basins will contain elevated salts (primarily manganese and sulphate).

Seepage of tailings water into groundwater will decrease at closure when tailings deposition ceases. The only seepage through the tailings will be from precipitation and infiltration will further decrease with revegetation and consolidation of the tailings.

Changes in groundwater flows may have an impact on socio-economics and land use, with decreased availability of groundwater and possibly surface waters for human consumption and agricultural use. Changes in the quality of groundwater may also impair groundwater for human consumption or other uses and may impair surface water quality.

3.7.5.2 Assessment Methods

Groundwater Consulting Services (GCS) (Pty) Ltd. carried out numerical modeling to predict impacts on groundwater conditions during planned tailings deposition activities, as well as the recovery of groundwater levels following closure (GCS, April 2005).

Two dimensional, steady state and transient 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 operational conditions were simulated by a steady state analyses and the output information was utilized to perform a transient state analysis for closure conditions.

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; and
- Post Closure - Year 100.

The tailings basins were analysed at the final embankment and tailings elevation for each case 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.

The water basins were analysed under varying design and operating conditions. Two design conditions were modelled for the water basins as follows:

- no basin liner allowing normal seepage to the foundation; and
- a synthetic basin liner system to minimize seepage flows.

Two operational conditions were analysed including normal operating levels and high to extreme operating levels to investigate impact to seepage rates under extreme wet periods. Parameters used for the seepage analyses are based on findings of the site investigations and results of laboratory testing conducted on tailings samples generated from a bulk sample bench scale program.

Flow gradients and velocities were incorporated into a contaminant transport model to simulate the migration of soluble chemical constituents within aquifers. Total dissolved solids (TDS), sulphate and manganese were identified as the most relevant indicator chemical parameters for groundwater modeling.

GCS (September 2005) subsequently used the groundwater model to optimize the arrangement of a groundwater recovery system designed to mitigate a salt plume in groundwater.

3.7.5.3 Impact Description Criteria

The assessment criteria used for hydrology are presented in Table 3.7-2.

Table 3.7-2 Impact Description Criteria and Numerical Scores for the Ambatovy Project – Hydrogeology

Resource	Direction[(a)]	Magnitude[(b)]	Geographic Extent[(c)]	Duration[(d)]	Reversibility[(e)]	Frequency[(f)]
mine site hydrogeology	**positive**, **negative** or **neutral** for the measurement endpoints	**negligible**: <5% change **low**: 5 to 10% change **moderate**: 10 to 30% change **high**: >30% change	**local**: effect restricted to the LSA **regional**: effect extends beyond the LSA into the RSA **beyond regional**: effect extends beyond the RSA	**short-term**: <3 years **medium-term**: 3 to 30 years **long-term**: >30 years	**reversible** or **irreversible**	**low**: occurs once **medium**: occurs intermittently (1 to 10 times per year) **high**: occurs frequently (>10 times per year)

(a) Direction: positive or negative effect for measurement endpoints, as defined for the specific component.

(b) Magnitude: degree of change to analysis endpoint.

(c) Geographic Extent: area affected by the impact.

(d) Duration: length of time over which the environmental effect occurs. Considers a three-year construction period and a 27-year operations period.

(e) Reversibility: effect on the resource (or resource capability) can or cannot be reversed.

(f) Frequency: how often.

3.7.5.4 Mitigation

To mitigate the effects of the tailings facility on groundwater flows and quality, the Ambatovy Project will implement the following measures:

- staged development to limit the amount of disturbed and exposed areas;
- develop tailings basins within former water basins;
- reduce seepage rates to groundwater by lining the water basins;
- install and operate a groundwater recovery system downstream of tailings basins throughout operations and 15-years post-closure to capture salt elevated groundwater; and
- return areas to natural runoff conditions through progressive and closure revegetation.

3.7.5.5 Results for Key Question HG-1: What Effect Will the Tailings Facility Have on Groundwater Flows and Consequently Downstream Surface Flows?

The blanketing effect of low permeability tailings deposited within the tailings basins will reduce recharge to groundwater as the tailings consolidate over time. This could reduce baseflow contribution to streams by up to 25%, a moderate magnitude of change to groundwater flow.

A groundwater recovery system, described in the next section (Section 3.7.5.6), will have an additional impact on groundwater levels; groundwater levels will be reduced by 1 to 5 m within an localized area that extends less than 1 km from the tailings facility, removing an estimated 640 to 1,040 m^3/day. GCS (October 2005) Drawing Nos. 11 and 12 in Volume I, Appendix 7.2 show the groundwater drawdown cone that will result from the groundwater recovery system, at the end of tailings deposition (Year 27) and at the end of the decommissioning phase (Year 42). Resettlement plans include relocation of residences located within 300 m of the tailings facility. Any impacts to groundwater users (i.e., shallow dug wells) will be limited to the approximately 700 m outside the resettlement area. The mitigation and residual social impacts arising from groundwater impacts is addressed in the social impact section (Volume D, Section 5.1).

Tables 3.7-3 and 3.7-4 show the estimated reduction in groundwater component to stream flows as a result of the interceptor borehole abstraction in the production phase and at the end of the decommissioning phase, respectively. GCS Drawing No. 3, included in Volume I, Appendix 7.2, shows the subcatchment drainage areas in relation to the development phases of the tailings facility.

Table 3.7-3 Reduction in Groundwater Component to Stream Flows – Operations Phase

Subcatchment Drainage Areas	Groundwater Component Reduction		
	Phase 1 – Year 14	Phase 2 – Year 20.5	Phase 3 – Year 27
Phase 1 Tailing Facility	-	-	-
Phase 2 Tailing Facility	9%	-	-
Phase 3 Tailing Facility	-	-	-
Phase 1 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%

Since the groundwater component of stream baseflow is small (about 6%), changes in groundwater flow have a relatively low magnitude of impact on surface water flows. The exception to this may be in the dry season when a larger portion of flow is expected from groundwater. However, baseline data collected in 2004-2005 indicates considerably larger dry season flows than expected from baseline groundwater modeling, which suggests that dry season flows may also be maintained by basin storage.

Table 3.7-4 Reduction in Groundwater Component to Stream Flows – End of Decommissioning Phase

Subcatchment Drainage Areas	Groundwater Component Reduction
A1	**69%**
A2	**8%**
B1	**75%**
B3	**1%**
C1	**46%**
C2	**15%**

The potential impact to surface water flows is described and evaluated in greater detail in the subsequent section on hydrology (Volume E, Section 3.8).

3.7.5.6 Results for Key Question HG-2: What Effect Will the Tailings Facility Have on Groundwater Quality?

Baseline groundwater quality studies identified that groundwater in the area does not currently meet WHO drinking water guidelines in the natural condition; aluminium was measured at ranges of <0.01 mg/l to 0.78 mg/l, compared with the WHO guideline value of 0.02 mg/l, and zinc ranged from 0.22 mg/l to 9.1 mg/l, compared with the WHO guideline value of 3 mg/l.

Testing of tailings slurry water indicated that tailings seepage is likely to have high concentrations of total dissolved solids, calcium, magnesium, sulphate, cobalt, manganese and nickel compared to background groundwater concentrations.

Initial contaminant transport modeling by GCS in April 2005 determined that the concentrations of salts in groundwater will increase as a result of placement of the tailings and seepage of tailings pore water into groundwater. Total dissolved solids (TDS), sulphate and manganese were used as indicator constituents to show the movement and relative concentrations of the resultant salt plume in groundwater, and manganese was predicted to exceed WHO guidelines. Without mitigation, the groundwater salt plume would extend up to 500 m downstream the tailings facility, and would likely affect surface water quality. To mitigate these impacts, a groundwater recovery system was designed to abstract impacted groundwater from immediately downgradient of the embankments of each tailings basin. The abstracted groundwater would be pumped into the lined water basins, ultimately reporting to the process plant or for ocean disposal.

The pumping wells will be complemented by a series of monitoring wells that will facilitate regular monitoring, positioned between each pumping well, to ensure the groundwater recovery system is meeting design objectives and groundwater downgradient will not adversely affect people and the environment. The monitoring wells could also be used as pumping wells if the interceptor system did not function as predicted.

Table 3.7-5 shows the schedule for implementation of the groundwater interceptor system at the various time intervals throughout the mine life. GCS October 2005 Drawing Nos. 13a through 13e in Volume I, Appendix 7.2 show the arrangement of pumping and monitoring wells from during Years 1, 14, 20, 27 and 42. GCS estimated that the groundwater recovery system will be required to operate for 15 years following closure at Year 27, to ensure groundwater and surface water downgradient of the facility is not substantially impacted. Following closure at Year 27, progressive reclamation will be substantially underway and tailings deposition will cease, and seepage of tailings seepage water into groundwater will decrease.

Table 3.7-5 Groundwater Recovery System Schedule 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-closure	27 - 42	32	22	54	1500-2000

As the groundwater model was used to determine the configuration of the groundwater interceptor system, the extent of the salt plume will be minimized. The expected TDS, sulphate and manganese concentrations in groundwater, as a result of the tailings facility and with mitigation using the groundwater recovery system, is described in the paragraphs that follow.

The modeled concentrations of TDS at the end of tailings deposition (Year 27), the end of operation of the groundwater recovery system (Year 42) as well as long-term (Year 100) are presented on GCS October 2005 Drawing Nos. 1a H4, 1b H4, and 1c H4 in Volume I, Appendix 7.2. The baseline TDS concentration ranges from 128 mg/l to 282 mg/l, compared to the WHO guideline value of 1,000 mg/l. According to the model, at Year 27 the TDS concentrations will be less than 600 mg/l only a short distance beyond the footprint of the tailings facility. This does not change appreciably by Year 42 when the groundwater recovery system is decommissioned. By Year 100, there has been some movement of increased TDS downgradient the tailings facility, with the maximum TDS concentration outside the tailings facility footprint <1,000 mg/l. Comparison of the maximum baseline TDS concentration (282 mg/l) with the predicted maximum TDS concentration at closure (600 mg/l) shows more than a 200% change, a high magnitude change. Nevertheless, TDS concentrations will remain below the corresponding WHO guideline value.

Baseline sulphate concentrations were very low, ranging from 1.4 to 3.8 mg/l, and were well below the WHO guideline value for sulphate of 250 mg/l. The WHO guideline value of 250 mg/l is an aesthetic value established for taste, as there is no health-based criterion for sulphate. Modeled concentrations of sulphate for Years 27, 42 and 100 (Volume I, Appendix 7.2, Drawing Nos. 2a H4, 2b H4, and 2c H4, respectively) show that like TDS concentrations, the plume is confined to the immediate vicinity of the tailings facility until the groundwater pumps are turned off in Year 42. By Year 100, in the absence of groundwater recovery, the sulphate plume has moved downgradient and spread. Sulphate concentrations remain for the most part below 100 mg/l with a smaller area where concentrations remain below the WHO guideline of 250 mg/l. The difference between the maximum baseline sulphate concentration (3.8 mg/l) and the predicted maximum sulphate concentration at closure (<250 mg/l) is two orders of magnitude, a high magnitude change. Nevertheless, sulphate concentrations will remain below the corresponding WHO guideline value.

Baseline manganese concentrations range from 0.02 mg/l to 0.27 mg/l in the natural condition, with the highest recorded baseline value being relatively close to the WHO drinking water guideline value of 0.4 mg/l. Contaminant transport modeling shows that at the end of operations in Year 27, manganese concentrations will range from 0.4 mg/l to 10 mg/l only a short distance downgradient of the tailings facility (Drawing No. 3a H4 in Volume I, Appendix 7.2). This will not change appreciably by Year 42 when the groundwater recovery system is decommissioned (Drawing No. 3b H4). By Year 100, however, the manganese plume, with concentrations ranging from 0.4 mg/l to 10 mg/l, will have migrated up to 1,000 m downgradient of the tailings facility. Two smaller areas immediately downgradient the tailings facility footprint, and within the 300 m buffer of the tailings facility designated for resettlement, will contain manganese at concentrations of 10 mg/l to 50 mg/l. The difference between the maximum baseline manganese concentration (just below the WHO guideline value of 0.4 mg/l) and the predicted maximum manganese concentration at closure (tens of milligrams per litre) is two orders of magnitude, a high magnitude change. Because manganese in the natural condition is relatively close to the WHO guideline value, any meaningful increase in manganese results in an exceedance of the guideline.

There is no expected change in aluminum or zinc concentrations, which already exceed the WHO drinking water guideline, as a result of operation of the tailings facility.

The potential to impact groundwater users within the affected area of elevated manganese is addressed in the social impact assessment (Volume D, Section 5.1).

The groundwater that discharges into watercourses and water bodies downstream of the tailings facility will be a combination of tailings seepage and unaffected background groundwater. The consequent impact to surface water quality from the groundwater salt plume is expected to be minimal, as groundwater contributions represent on average 6% of baseflow.

A mass balance model was used to conservatively assess changes in water quality due to seepage from the tailings facility and reductions in flows downstream of the tailings facility. Volume E, Section 3.10 describes the assessment methods and impact assessment of the resultant changes in surface water quality that are predicted to result, in part, from changes to groundwater quality.

3.7.6 Impact Analysis

3.7.6.1 Residual Impacts

Results of the impact analysis indicate that during construction, with the construction of the tailings facility embankments and lining of the water basin, impacts to groundwater flows and quality will be negligible (less than 5% change) and reversible.

Starting with operation and into the long-term, groundwater levels at the tailings facility will be lowered and groundwater contributions to downstream streamflows will be reduced. This is due to both the placement of low permeability tailings and lined water basins, as well as operation of a groundwater recovery system. The effect on groundwater flows are of a high magnitude (>30%) according to the rating system for hydrogeology. The impact of this change on potential groundwater use is addressed in Volume D, Section 5.1. Groundwater provides an estimated 6% of baseflow in downstream surface waters, and thus the overall magnitude of groundwater flow reductions to surface waters is low.

Groundwater quality will be influenced by the tailings facility. Even with mitigation through operation of a groundwater interceptor system, manganese concentrations in groundwater above the WHO guideline of 0.4 mg/L (up to

10 mg/L) may extend about 1,000 m downgradient (east of) the tailings facility. A smaller area concentrated immediately downgradient the tailings facility is predicted to contain manganese at concentrations ranging from 10 mg/l to 50 mg/l. This represents a high magnitude change.

The magnitude of change of both groundwater flows and groundwater quality resulting from the tailings facility during operation and closure phases is high, based on the percent change predicted for each, relative to baseline conditions. While each high magnitude rating is given a correspondingly high environmental consequence rating based on the assessment methodology, these impacts are related solely to physical changes to the environment. Consequent impacts of the changes in groundwater flow and quality on surface water and human use are evaluated in other report sections.

Table 3.7-6 Residual Impact Classification for Hydrogeology

Phase	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Issue: Impacts to Groundwater Levels							
construction	n/a	negligible	local	short-term	reversible	high	negligible
operation/ closure	negative	high	local	long-term	reversible	high	high
Issue: Impacts to Surface Water Flows							
construction	negative	negligible	local	short-term	reversible	high	negligible
operation/ closure	negative	low	local	long-term	reversible	high	low
Issue: Impacts to Groundwater Quality							
construction	neutral	negligible	local	short-term	reversible	high	negligible
operation/ closure	negative	high	local	long-term	reversible	high	high[a]

[a] Related solely to physical changes. Consequent social effects addressed in Volume D, Section 5.1.

Changes in groundwater flow and quality may influence groundwater use if there are shallow groundwater wells within the affected area, and this is addressed in the social impact assessment (Volume D, Section 5.1). The social impact assessment identified proposed mitigation such that the residual environmental effects on human use is of low environmental consequence.

Resultant changes in surface water flows are addressed within the hydrology section (Volume E, Section 3.8) and resultant changes in surface water quality in the water quality section (Volume E, Section 3.10).

3.7.6.2 Prediction Confidence

A medium level of uncertainty is associated with the substance concentrations in seepage. The substance concentrations in seepage were estimated using just one slurry sample. Once operations begin, the treatment process can be controlled to effectively meet the predicted water quality for the sample.

The resultant predicted concentrations of solutes in groundwater, arising from tailings seepage, is medium, based in part on the prediction confidence of tailings seepage water quality, and in part that contaminant transport modelling assumed conservative behaviour of its constituents (i.e., no attenuation or geochemical transformations of water quality substances).

The prediction confidence associated with the effect of groundwater abstraction on the groundwater levels at the mine area is moderate, given that the modeling is based upon aquifer parameters derived from in-situ testing but in a relatively modest number of boreholes (6).

The interaction between surface water and groundwater in the project area is not well understood, particularly during the dry season in locations where surface flows may be dominated by groundwater inflows. The impact ratings are based on a simple hydrologic model that assesses average monthly conditions based on a reasonable estimate of annual rainfall and runoff. For these average conditions, the prediction confidence is considered medium. For dry monthly conditions, however, flow estimates are based on a runoff depth derived from a single season of hydrometric monitoring and the interaction with groundwater may be more significant. Based on the uncertainties associated with these parameters, the prediction confidence for dry season conditions is considered low.

3.7.6.3 Monitoring

Additional groundwater investigations and monitoring prior to construction will allow for groundwater model refinement. Monitoring during operations will include regular monitoring of groundwater levels and quality in observation monitoring wells positioned between pumping wells of the groundwater recovery system, situated downgradient of the tailings basin embankments. Continued monitoring of streamflows within the affected basins is recommended to support an improved understanding of hydrologic response in the study area. Daily streamflow records can be evaluated along with recorded climate data (e.g., rainfall and evaporation) at nearby Toamasina to further assess water availability for various biophysical and social needs.

Monitoring of the effectiveness of erosion control measures, slope stability and reclamation success are described in Volume B, Section 6.

3.7.7 Conclusions

During operation, the tailings facility will have effects on both groundwater flows and quality. Groundwater flows and quality will experience high magnitude changes (i.e., >30% change from baseline) due to the blanketing effect of the tailings, seepage of tailings pore water, and the operation of the groundwater recovery system. The result is high environmental consequence physical changes to groundwater flows and groundwater quality, although these effects decline rapidly with distance. With mitigation utilizing the groundwater interceptor system, the potential impacts to water quality in downstream surface flows will be minimized.

Changes to groundwater flows and quality have consequent social impacts, with respect to effects of lowered groundwater levels and impaired groundwater quality on groundwater use for human consumption or agriculture. The extent of a lowered groundwater table and elevated manganese is relatively localized but does extend beyond the 300 m buffer assigned around the tailings facility. The impacts of these changes, evaluated in the social impact assessment (Volume D, Section 5.1), were determined to be low following mitigation.

In addition, reduced groundwater flow has a subsequent effect on surface water flows. Since groundwater contributions to stream baseflow is estimated at about 6%, the high magnitude change to groundwater flow translates to a low magnitude effect on surface water flows, discussed further in the section on hydrology (Volume E, Section 3.8).

The resultant effect of groundwater impacts (primarily elevated manganese) on surface water quality is relatively minor, considering the small contribution of groundwater to stream flows. Mass balance modeling of surface water quality, considering contributions of constituents in groundwater, is evaluated in detail in the section on water quality (Volume E, Section 3.10).

3.8 SURFACE WATER HYDROLOGY

3.8.1 Introduction

Development of the tailings facility will involve the collection and diversion of surface runoff in the upper basins of the affected watersheds. The facility will also include a series of interceptor wells downgradient of the embankments that will collect seepage and return it to the water pond. As a result of these diversions, flows in the downstream valley will be reduced and the availability of water for other users (i.e., human and animal consumption, irrigation and fish habitat) may be affected. Long-term changes in flows and water levels could also affect the channel morphology of receiving streams.

Regional climate and hydrologic information have been compiled to characterize baseline conditions in the tailings area (Volume I, Appendix 8.1). The available baseline information is used in the following sections to evaluate potential effects of the Ambatovy Project (the project) on streamflow and sediment yield.

3.8.2 Study Areas

The tailings facility is located in the upper valley of three parallel tributaries to the Ambolona River. As shown in Volume A, Figure 7.2-3, the hydrology local study area (LSA) extends from the headwaters of the valleys, along the main stem of the Ambolona River, to the confluence with the Vorinkina River about 2 km downstream of the south valley. This endpoint was chosen to enable the assessment of combined impacts from each of the basins on the Ambolona River, and because any impacts from the tailings facility would be greatly reduced downstream of the confluence with the larger Vorinkina River.

3.8.3 Baseline Summary

3.8.3.1 Introduction

Baseline conditions in the tailings area were characterized by analyzing available climate and hydrologic (streamflow) data. A summary of the climate and hydrology baseline study is provided in the following sections. Details can be found in Volume I, Appendix 8.1.

3.8.3.2 Methods

Information on Madagascar's climate was primarily obtained from Chaperon et al. (1993). Climate information was also obtained from the World

Meteorological Organization, from rainfall stations at regional railway stations, and from the Madagascar Ministry of Public Works and Transport, Meteorology Branch.

Site-specific streamflow data were collected between March 2004 and March 2005 at four locations in the tailings area, including three stations along the upper Amobolona River and one station on 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 daily 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.

3.8.3.3 Results

The tailings facility is located near the major port of Toamasina. There are long-term climate records available for Toamasina (1950 to 2004) from which mean monthly and annual temperatures and precipitation have been derived. Streamflow characteristics are based on results from the 2004 to 2005 hydrometric monitoring program.

Toamasina has a mean annual temperature of 24.6°C, with August being the coldest month (21.7°C) and February being the warmest month (27.1°C). The mean annual precipitation is about 3,300 mm (Table 3.8-1). March is the wettest month (473 mm) and October is the driest month (115 mm). Historical records suggest that the mean annual precipitation can vary from about 30% lower to about 60 % higher. Estimates of maximum 24-hour rainfall amounts are summarized in Table 3.8-2. Actual evapotranspiration for the tailings area is estimated at 1,300 mm per year. Estimates of stream flow runoff are summarized in Table 3.8-3.

Table 3.8-1 Mean Monthly Rainfall (mm) for Tailings Facility

Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
155	311	403	425	479	315	271	263	276	200	128	116	3343

Reference: Madagascar Ministry of Public Works and Transport, Meteorology Branch 2005.

Table 3.8-2 Maximum Daily Precipitation Frequency Analysis for Tailings Facility

	Return Period					
	2-yr	5-yr	10-yr	20-yr	50-yr	100-yr
maximum daily precipitation (mm)	159	224	273	326	402	465

Reference: Madagascar Ministry of Public Works and Transport, Meteorology Branch 2005.
Note: Daily precipitation totals are from 7 am to 7 am.

Table 3.8-3 Derived Monthly and Annual Runoff for Tailings Facility

Monthly Runoff (mm)			Annual Runoff (mm)
Early Dry Season (April/May)	Late Dry Season (October/November)	Peak Wet Season (January – March)	
150	50	100 (upper basin) 225 (lower basin)	1,700

Note: Based on data from the 2004-2005 monitoring program.

3.8.4 Issue Scoping

Hydrology issues related to the project were identified through consultation with stakeholders and by reviewing previous environmental assessments for resource developments in Madagascar and elsewhere. The following hydrology issues were identified (Volume A, Section 6):

- changes in flows, water levels and sediment loads that could alter channel morphology and sediment concentrations; and
- changes in water availability for various uses (human and animal consumption, irrigation and aquatic habitat).

The key indicators of change due to the project are flows, water levels, sediment concentrations and channel morphology. These changes may also have an effect on water quality (Section 3.10 in this volume), fish health (Section 4.3), vegetation (wetlands)(Section 4.1), and socioeconomic components of the project (Section 5.1).

The Key Questions for the hydrology surrounding the tailings facility are:

Key Question H-1 What Effect Will the Tailings Facility Have on Flows and Water Levels in Water Bodies?

Key Question H-2 What Effect Will the Tailings Facility Have on Sediment Levels in Water Bodies?

The impact pathways between project activities, environmental changes, key questions, and assessment results are shown in Volume H, Appendix H-9.

3.8.5 Impact Assessment

3.8.5.1 Impact Pathway Evaluation

Project activities during construction, operation and closure may result in the following: i) changes in flows and water levels in receiving water bodies; and ii) changes in sediment levels.

During construction there will be disturbance to the landscape as a result of site clearing and the development of infrastructure. Surface runoff characteristics and natural drainage patterns will be affected. Landscape disturbance, along with the exposure of soil to erosion, may increase sediment yield and transport to receiving water bodies.

During operation, the tailings facility will divert natural runoff in the upper watersheds and will result in reduced flows at downstream locations. Reduced groundwater contribution in downstream reaches will also occur due to lower infiltration rates in the tailings facility and groundwater interception by the wells located downgradient of the embankments. Diversion of runoff from the upper watersheds will also restrict sediment movement from the upper basin to lower reaches. The tailings embankments, however, could act as a sediment source and could result in increased sediment yield to the lower basin.

Long-term changes in flows and water levels, in conjunction with changes in sediment supply, could also affect channel morphology as the channel attempts to reach new equilibrium conditions. However, as discussed in Section 3.8.5.5., impacts on flows, water levels, and sediment levels will only occur during operation of the tailings facility and will therefore be of medium-term duration. The changes in key indicators also involve reductions in flows which could result in sediment deposition within channels and channel aggradation (in contrast to the erosion and channel degradation that can occur with increased flows). It is important to note that the channels downstream of the tailings facility have been heavily altered by local farmers, and are not natural, equilibrium streams. It is therefore difficult to predict the morphological changes that could occur in these streams as a result of flow and sediment supply changes. Furthermore, most changes are expected to be reversed at closure when natural flow conditions are re-established.

At closure, surface runoff will be returned to the natural receiving water bodies. Minor changes in flows, water levels, and sediment levels are expected in the receiving stream reaches due to reduced groundwater contribution resulting from either groundwater interception or reduced infiltration in the upper tailings watersheds. Pumping for groundwater interception is planned for about 15 years following closure or until sufficient flushing has occurred and acceptable water quality is established at all surface water downstream locations.

Changes in flows, water levels, and sediment levels in receiving water bodies may also affect water quality, fish and aquatic resources, socioeconomics and land use. Water users are described in the socioeconomic and land use baseline reports (Volume K, Appendices 1.1 and 3.1) and effects of hydrologic changes on agriculture are described in the land use EA report (Volume E, Section 5.3).

3.8.5.2 Assessment Methods

Changes in flows in receiving streams were evaluated based on changes in estimated surface water contribution and groundwater contribution at various locations downstream of the tailings facility. Baseline runoff characteristics were derived from field observations in 2004-2005 and were used to estimate pre-development surface water and groundwater contributions to streamflow. Surface runoff during operations was estimated by considering the reduced drainage areas resulting from runoff diversion in the upper basins. Groundwater contributions to stream flow were obtained from a saturated groundwater model of the area, as described in Section 3.7. Stream flows for post-closure conditions were also evaluated.

Additional details regarding assessment methods are included in Section 3.8.5.5. Changes in water levels at three hydrometric monitoring locations were evaluated based on the expected changes in flows and the available stage-discharge (rating) curves and cross-sectional survey information.

Changes in sediment levels were evaluated qualitatively based on expected changes in drainage areas and streamflows.

3.8.5.3 Impact Description Criteria

The assessment criteria used for hydrology are presented in Table 3.8-4.

Table 3.8-4 Impact Description Criteria and Numerical Scores for the Ambatovy Project – Surface Water Hydrology

Resource	Direction[(a)]	Magnitude[(b)]	Geographic Extent[(c)]	Duration[(d)]	Reversibility[(e)]	Frequency[(f)]
surface water hydrology	**positive**, **negative** or **neutral** for the measurement endpoints	**negligible**: <5% change **low**: 5 to 10% change **moderate**: 10 to 30% change **high**: >30% change	**local**: effect restricted to the LSA **regional**: effect extends beyond the LSA into the RSA **beyond regional**: effect extends beyond the RSA	**short-term**: <3 years **medium-term**: 3 to 30 years **long-term**: >30 years	**reversible** or **irreversible**	**low**: occurs once **medium**: occurs intermittently (1 to 10 times per year) **high**: occurs frequently (>10 times per year)

(a) Direction: positive or negative effect for measurement endpoints, as defined for the specific component.
(b) Magnitude: degree of change to analysis endpoint.
(c) Geographic Extent: area affected by the impact.
(d) Duration: length of time over which the environmental effect occurs. Considers a three-year construction period and a 27-year operations period.
(e) Reversibility: effect on the resource (or resource capability) can or cannot be reversed.
(f) Frequency: how often the environmental effect occurs.

3.8.5.4 Mitigation

To mitigate the effects on flows, water levels and sediment levels, the Ambatovy Project will implement the following measures:

- stage development to limit the amount of disturbed and exposed areas;
- monitor changes in climate conditions and downstream flows and suspended sediment concentrations;
- implement an emergency response plan to advise downstream residents of potential spillway releases during extreme storm conditions;
- use erosion control measures, including the development of stable embankment slopes and prompt revegetation (refer to Volume D, Section 3.8 for other examples of best management practices for erosion and sediment control);
- return areas to natural runoff conditions through grading and revegetation; and
- direct streams and drainage paths to natural receiving water bodies.

3.8.5.5 Results for Key Question H-1: What Effect Will the Tailings Facility Have on Flows and Water Levels in Water Bodies?

Development of the tailings facility will involve three operational phases, in which tailings are deposited in one tailings basin after another. The facility will divert water from the upper watersheds and will also intercept groundwater downgradient of the embankments. The operational phases will be followed by two closure phases. The initial closure phase, which is expected to continue until approximately Year 42, will include pumping of the interceptor well system. Impacts within each basin have been assessed for the operational phase associated with maximum watershed disturbance and water diversion, as well as for both closure phases.

The surface water management systems associated with each phase are described in Table 3.8-5 and illustrated in Figures 3.8-1 to 3.8-4. Basin A refers to the north valley (also referred to as TA-11), which is drained by Ambolona Tributary 1. Basin B refers to the middle valley (also referred to as TA-10), which is drained by Ambolona Tributary 2. Basin C refers to the south valley, which is drained by Ambolona Tributary 3.

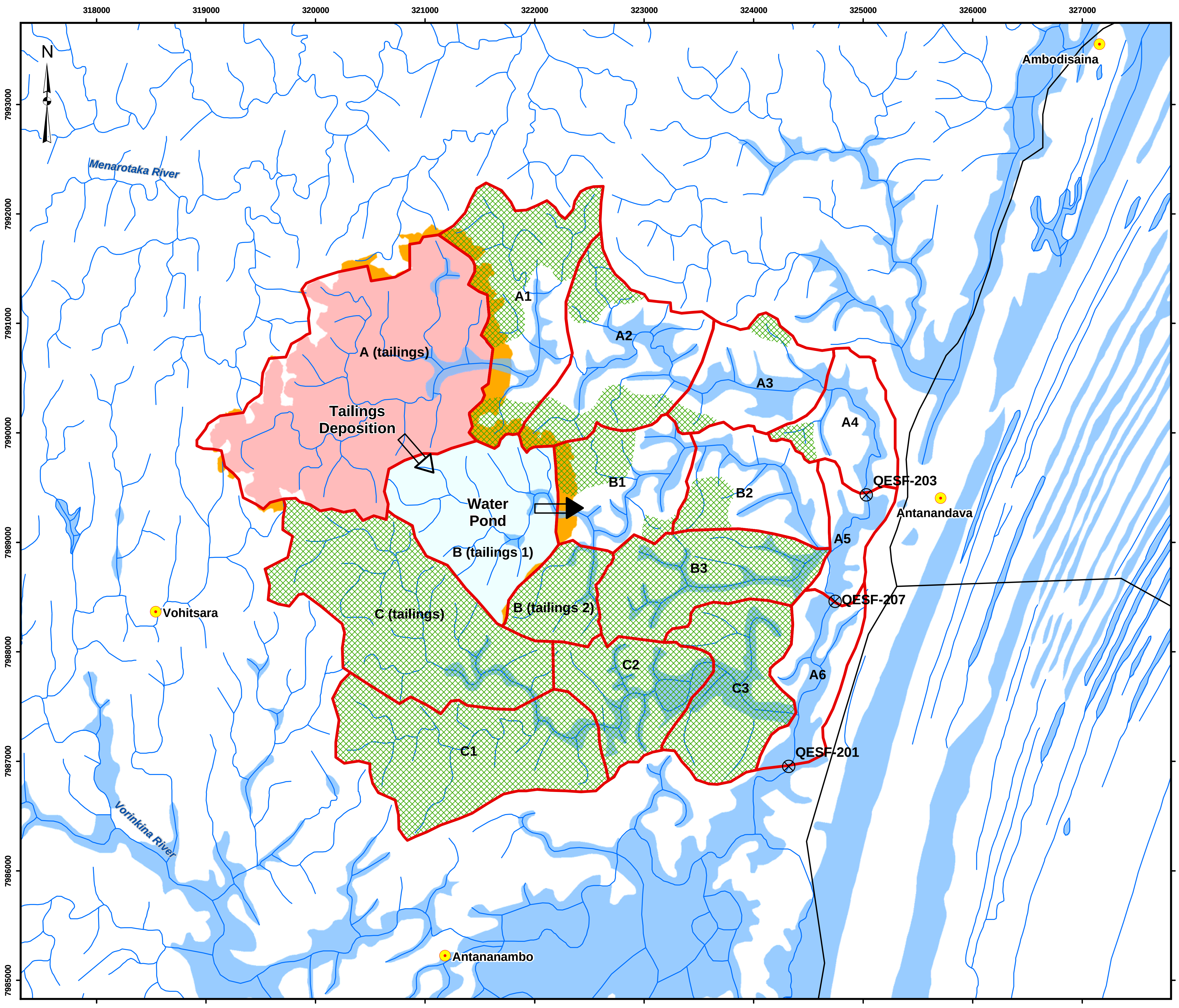
Figures 3.8-1 to 3.8-4 show the location of the tailings facility in the upper watersheds of the three valleys and the stream segments considered in the assessment. During operation, runoff in the upper basins will be diverted to the water pond and will not contribute to downstream flows along the main stem of the valley rivers. Excess water from supernatant and local runoff will be discharged to the ocean and a portion re-used at the plant. With the elimination of runoff from the upper watersheds, an initial estimate of the reduction in downstream flows can be calculated from the reduction in drainage area due to tailings pond development, as summarized in Table 3.8-6.

A more detailed analysis of changes to downstream flows addresses the changes in surface runoff as well as changes in groundwater contribution. Operation of the tailings facility is expected to result in reduced groundwater contribution to downstream watercourses due to groundwater seepage collection by the interceptor wells and due to overall lower infiltration rates through the tailings. The greatest reduction in groundwater flux coincides with the maximum watershed disturbance in Basins 1 and 3, in Years 14 and 20, respectively (A. Marais pers comm. 2005). For Basin 2, the greatest reduction in groundwater occurs in Phase 1 (before Year 14) as a result of lining within the water pond and reduced infiltration rates from this area (A. Marais per comm. 2005). The groundwater interception system will continue to operate after closure for about 15 years in order to manage the groundwater quality reaching the downstream surface water. After pumping has ended, groundwater levels will recover and will return to near-baseline conditions in the long term.

Table 3.8-5 Description of Development Phases and Potential Changes in Runoff Characteristics

Scenario	Tailings Discharge Location	Water Pond Location	Basin Disturbance and Potential Change in Downstream Runoff		
			Basin A (Valley TA-11)	Basin B (Valley TA-10)	Basin C (South Valley)
operations year 14 - end of phase 1	A(tailings)	B(tailings1) – upper northwest area of Basin B	• 100% disturbance in upper basin due to tailings deposition • runoff from upper basin directed to water pond resulting in reduced flows in downstream reaches • tailings groundwater seepage collected by interceptor wells and pumped back to water pond	• B(tailings1) used as water pond resulting in 65% disturbance of the upper basin watershed area • runoff from this area collected in the pond • pond water discharged to ocean and a portion reused at the plant	• no land disturbance or diversion of water • no change in streamflows
operations year 20 - end of phase 2	C(tailings)	B(tailings1) – upper northwest area of Basin B	• 100% reclaimed • runoff from the upper basin returned to natural receiving water body (small sedimentation pond remains) • tailings groundwater seepage collected by interceptor wells and pumped back to water pond	• B(tailings1) used as water pond resulting in 65% disturbance of the upper basin • runoff from this area collected in the pond • pond water discharged to ocean and a portion reused at the plant	• 100% disturbance in upper basin due to tailings deposition • runoff from upper basin directed to water pond resulting in reduced flows in downstream reaches • tailings groundwater seepage collected by interceptor wells and pumped back to water pond
operations year 27 - end of phase 3	B(tailings)	B(tailings2) – southeast of Water Pond for Phases 1 and 2	• 100% reclaimed • runoff from the upper basin returned to natural receiving water body (small sedimentation pond remains) • tailings groundwater seepage collected by interceptor wells and pumped back to water pond	• 100% disturbance in upper basin (65% for tailings disposal; 35% for water pond) • runoff from upper basin directed to water pond resulting in reduced flows in downstream reaches • tailings groundwater seepage collected by interceptor wells and pumped back to water pond Pond water discharged to ocean and a portion reused at the plant	• 100% reclaimed • runoff from the upper basin returned to natural receiving water body (small sedimentation pond remains) • tailings groundwater seepage collected by interceptor wells and pumped back to water pond
closure year 42 -end of interceptor well pumping	not applicable	not applicable	• 100% reclaimed • runoff from the upper basin returned to natural receiving water body (small sedimentation pond remains) • pumping of interceptor wells ends; groundwater levels near wells begin to recover	• 100% reclaimed • runoff from the upper basin returned to natural receiving water body (small sedimentation pond remains) • pumping of interceptor wells ends; groundwater levels near wells begin to recover	• 100% reclaimed • runoff from the upper basin returned to natural receiving water body (small sedimentation pond remains) • pumping of interceptor wells ends; groundwater levels near wells begin to recover
–closure year 100 - long term	not applicable	not applicable	• • as above (year 42) • groundwater levels near wells have recovered	• As above (year 42) • groundwater levels near wells have recovered	• as above (year 42) • groundwater levels near wells have recovered

Note: Basins A, B, and C are associated with Ambolona Tributaries 1, 2 and 3, respectively. They are also referred to as Valley TA-11, Valley TA-10, and the South Valley.



LEGEND

- POPULATION CENTRE
- WATER QUALITY AND STAFF GAUGE (2004)
- SUPERNATANT FLOW DIRECTION
- RETURN WATER TO PLANT
- ROAD
- STREAM OR RIVER
- DELINEATED WATERSHED
- SEASONALLY FLOODED AREA OR STANDING WATER
- TAILINGS FACILITY
- TAILINGS FACILITY EMBANKMENT AREAS
- WATER POND
- AREAS NOT AFFECTED BY TAILINGS IMPOUNDMENT (NO REDUCTION IN FLOWS EXPECTED)

REFERENCE

Datum: WGS 84 Projection: UTM Zone 39S

1 0 1

SCALE 1:35,000 KILOMETRES

PROJECT

AMBATOVY PROJECT

TITLE

TAILINGS FACILITY WATER MANAGEMENT - YEAR 14 (END OF PHASE 1)

Golder Associates
Calgary, Alberta

PROJECT No. 03-1322-172.7000			SCALE AS SHOWN	REV. 0
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GIS	TN	12 Sep. 2005	**FIGURE: 3.8-1**	
CHECK	GJ	09 Feb. 2006		
REVIEW	DM	09 Feb. 2006		

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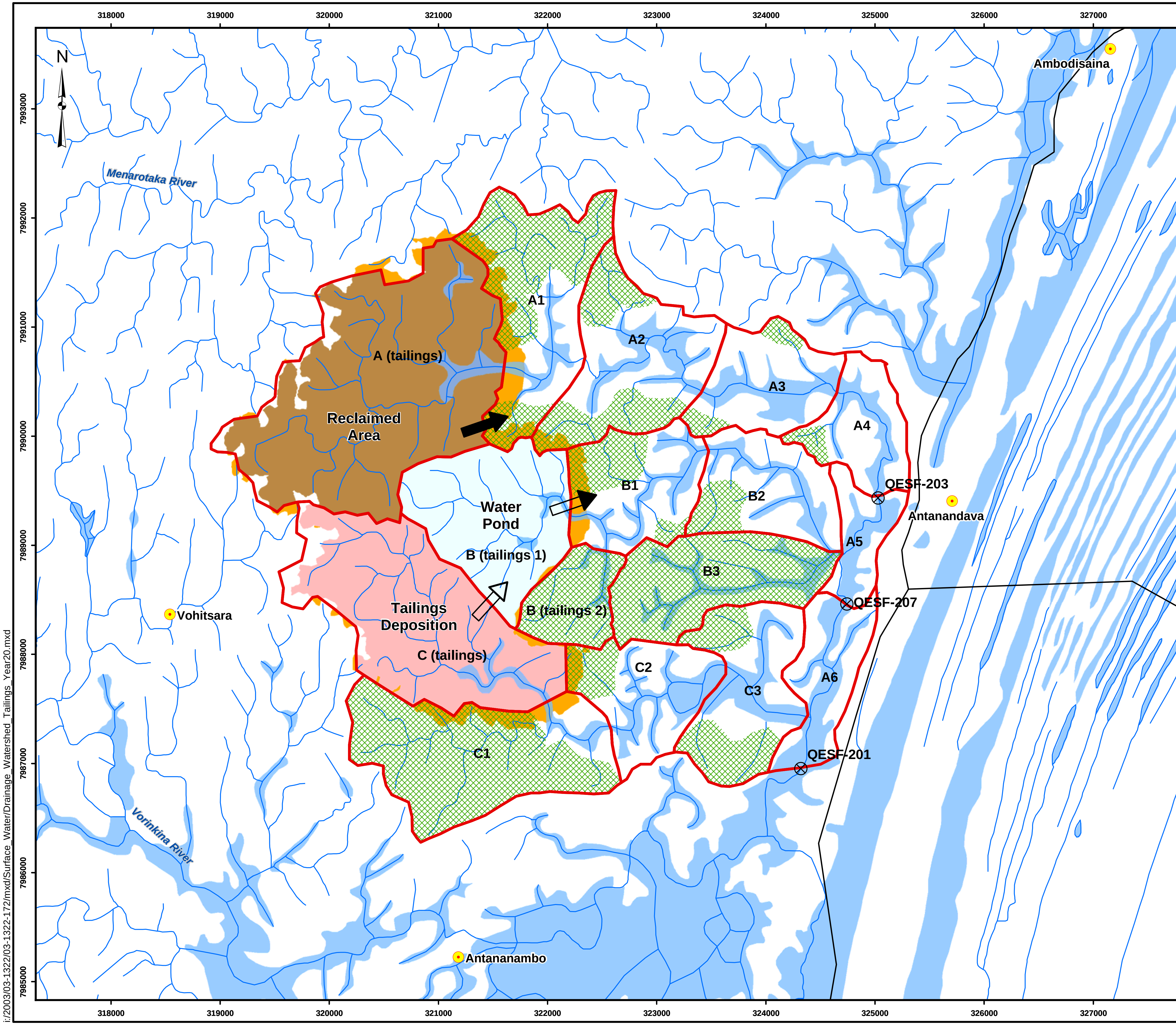

LEGEND

- POPULATION CENTRE
- WATER QUALITY AND STAFF GAUGE (2004)
- SUPERNATANT FLOW DIRECTION
- RETURN WATER TO PLANT
- CLOSURE RUNOFF DIRECTION
- ROAD
- STREAM OR RIVER
- DELINEATED WATERSHED
- RECLAIMED AREA
- SEASONALLY FLOODED AREA OR STANDING WATER
- TAILINGS FACILITY
- TAILINGS FACILITY EMBANKMENT AREAS
- WATER POND
- AREAS NOT AFFECTED BY TAILINGS IMPOUNDMENT (NO REDUCTION IN FLOWS EXPECTED)

REFERENCE

Datum: WGS 84 Projection: UTM Zone 39S

1 0 1

SCALE 1:35,000 KILOMETRES

PROJECT

AMBATOVY PROJECT

TITLE

TAILINGS FACILITY WATER MANAGEMENT - YEAR 20 (END OF PHASE 2)

Golder Associates
Calgary, Alberta

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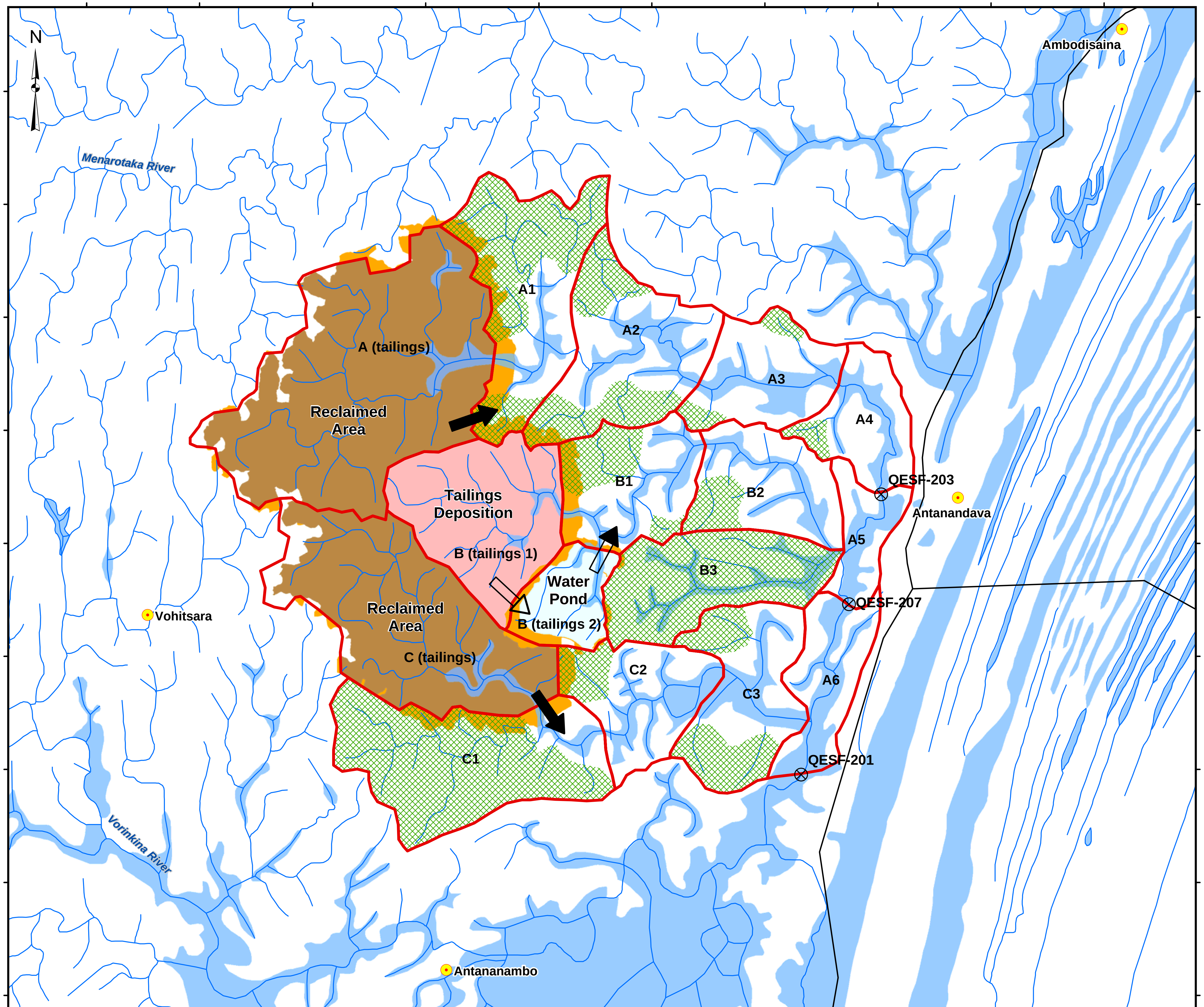
GIS	TN	12 Sep. 2005		
CHECK	GJ	09 Feb. 2006		
REVIEW	DM	09 Feb. 2006		

FIGURE: 3.8-2



PROJECT

AMBATOVY PROJECT

TITLE

TAILINGS FACILITY WATER MANAGEMENT - YEAR 27 (END OF PHASE 3)

Golder Associates
Calgary, Alberta

PROJECT No. 03-1322-172.7000		SCALE AS SHOWN	REV. 0
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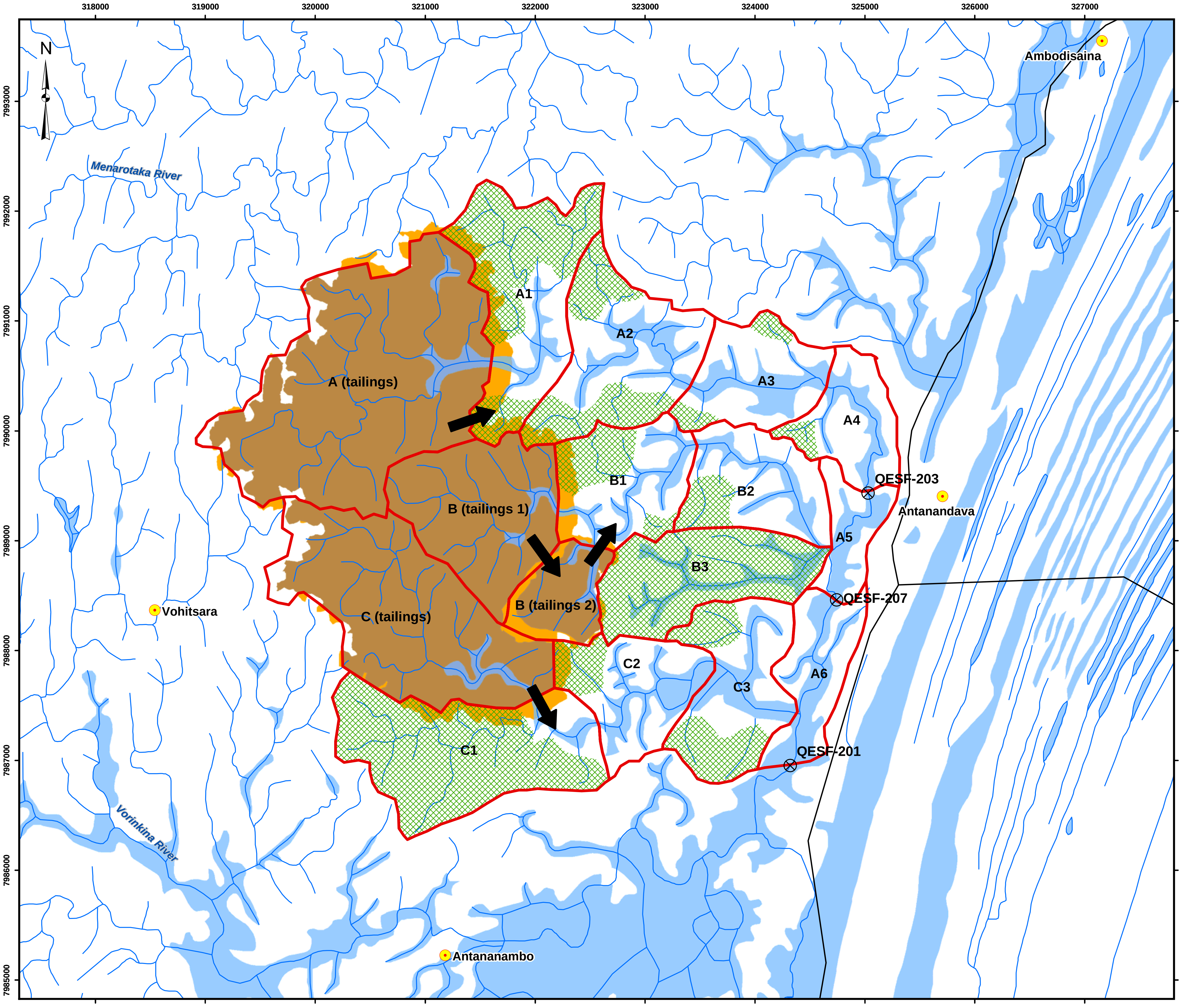
GIS	TN	04 Oct. 2005	
CHECK	GJ	09 Feb. 2006	
REVIEW	DM	09 Feb. 2006	

FIGURE: 3.8-3

i:/2003/03-1322/03-1322-172/mxd/Surface_Water/Drainage_Watershed_Tailings_Year27.mxd



LEGEND

- POPULATION CENTRE
- WATER QUALITY AND STAFF GAUGE (2004)
- CLOSURE RUNOFF DIRECTION
- ROAD
- STREAM OR RIVER
- DELINEATED WATERSHED
- RECLAIMED AREA
- SEASONALLY FLOODED AREA OR STANDING WATER
- TAILINGS FACILITY EMBANKMENT AREAS
- AREAS NOT AFFECTED BY TAILINGS IMPOUNDMENT (NO REDUCTION IN FLOWS EXPECTED)

REFERENCE

Datum: WGS 84 Projection: UTM Zone 39S

1 0 1

SCALE 1:35,000 KILOMETRES

PROJECT

AMBATOVY PROJECT

TITLE

TAILINGS FACILITY WATER MANAGEMENT - CLOSURE

Golder Associates
Calgary, Alberta

PROJECT No. 03-1322-172.7000			SCALE AS SHOWN	REV. 0
DESIGN	GJ	22 Apr. 2005		
GIS	TN	04 Oct. 2005		
CHECK	GJ	09 Feb. 2006	FIGURE: 3.8-4	
REVIEW	DM	09 Feb. 2006		

i:/2003/03-1322/03-1322-172/mxd/Surface_Water/Drainage_Watershed_Tailings_Closure.mxd

Table 3.8-6 Drainage Areas Downstream of the Tailings Facility

Basin	Basin Segment	Basin Segment Area (km^2)	Total Drainage Area (km^2)	Area Diverted by Tailings Facility (km^2)	Non-Affected Drainage Area (km^2)	Reduction in Drainage Area with Diversion
A	A(tailings)	4.0	4.0	3.8	0.2	94%
	A1	1.8	5.9	3.8	2.1	64%
	A2	1.7	7.6	3.8	3.8	50%
	A3	1.1	8.7	3.8	4.9	44%
	A4	0.8	9.5	3.8	5.7	40%
	A5	0.5	16.1	7.1	10.6	34%
	A6	0.8	24.4	10.0	14.4	41%
B	B(tailings1)	1.7	1.7	1.7	0.0	100%
	B(tailings2)	0.6	0.6	0.6	0.0	100%
	B1	1.2	3.6	2.4	1.2	66%
	B2	1.1	4.7	2.4	2.3	50%
	B3	1.4	1.4	0.0	1.4	0%
C	C(tailings)	2.7	2.7	2.9	0.0	100%
	C1	2.2	5.0	2.9	2.2	55%
	C2	1.1	6.1	2.9	3.3	45%
	C3	1.4	7.4	2.9	4.7	37%

Changes in streamflow within the various tailings sub-basins were calculated for average conditions based on an average monthly runoff of 142 mm, as derived from a mean annual runoff of about 1,700 mm. A similar analysis was completed for dry conditions using a monthly runoff of 50 mm, as observed during the 2004-2005 dry season. Results of the analyses are presented in Tables 3.8-7 and 3.8-8. The baseline, operational and post-closure flows represent the total flow in a stream, which is derived from both direct surface runoff and groundwater inflows.

During operation, reductions in streamflow for each reach are roughly the same for both the average month and dry month scenarios. They are also comparable to the percent reductions in drainage areas shown in Table 3.8-6, which indicate a much higher sensitivity to changes in drainage area than to changes in groundwater contribution. Although the groundwater flux will decrease due to interception and reduced permeability in the tailings area, the groundwater component to total flow appears to be small. The exception to this may be in the dry season when a larger portion of flow is expected from groundwater. However, baseline data collected in 2004 to 2005 indicate considerably larger dry season flows than expected from baseline groundwater modelling. This suggests that dry season flows may also be maintained by basin storage, or that the available groundwater data reflect large uncertainties.

Table 3.8-7 Estimated Reductions in Streamflow in Downstream Reaches – Average Month

Basin Characteristics			Baseline			Operations				Closure - End of Pumping (Year 42)		Closure - Long-term	
Basin	Reach Name	Sub-Basin Area (km^2)	Runoff (mm)	Flow (m^3/d)	Flow (m^3)	Year	Reduction in Drainage Area	Flow (m^3/d)	Flow Reduction[(a)] (%)	Flow (m^3/d)	Flow Reduction (%)	Flow (m^3/d)	Flow Reduction[(a)] (%)
A	A(tailings)	4	142	19,156	574,691	14	94%	-	-	-	-	-	-
	A1	5.9	142	27,900	837,006		64%	9,712	65%	26262	6%	26,490	5%
	A2	7.6	142	36,027	1,080,810		50%	17,893	50%	34346	5%	34,617	4%
	A3	8.7	142	41,051	1,231,529		44%	23,026	44%	39370	4%	39,641	3%
	A4	9.5	142	45,008	1,350,229		40%	26,998	40%	43327	4%	43,598	3%
	A5	16.1	142	76,207	2,286,200		34%	49,990	34%	73,413	4%	74,067	3%
	A6	24.4	142	115,493	3,464,800		41%	69,950	39%	110,957	4%	112,133	3%
B	B(tailings1)	1.7	142	8,174	245,226	27	100%	-	-	-	-	-	-
	B(tailings2)	0.6	142	2,982	89,460		100%	-	-	-	-	-	-
	B1	3.6	142	16,899	506,982		66%	5,809	66%	15792	7%	16,169	4%
	B2	4.7	142	22,229	666,880		50%	11,360	49%	21122	5%	21,499	3%
	B3	1.4	142	6,807	204,196		0%	6,797	0%	6802	0%	6,807	0%
C	C(tailings)	2.7	142	12,973	389,205	20	100%	-	-	-	-	-	-
	C1	5	142	23,441	703,242		55%	10,132	57%	21719	7%	22,231	5%
	C2	6.1	142	28,721	861,630		45%	15,438	46%	26978	6%	27,501	4%
	C3	7.4	142	35,159	1,054,777		37%	21,876	38%	33416	5%	33,938	3%

[(a)] Reduction in flow along the main stem of the stream at the downstream end of the reach.

Table 3.8-8 Estimated Reductions in Streamflow in Downstream Reaches – Dry Season Month

Basin Characteristics			Baseline			Operations				Closure - End of Pumping (Year 42)		Closure - Long-term	
Basin	Reach Name	Sub-Basin Area (km^2)	Runoff (mm)	Flow (m^3/d)	Flow (m^3)	Year	Reduction in Drainage Area	Flow (m^3/d)	Flow Reduction[(a)] (%)	Flow (m^3/d)	Flow Reduction (%)	Flow (m^3/d)	Flow Reduction[(a)] (%)
A	A(tailings)	4	50	6,745	202,356	14	94%	-	-	-	-	-	-
	A1	5.9	50	9,824	294,720		64%	3,289	67%	8186	17%	8,414	14%
	A2	7.6	50	12,686	380,567		50%	6,205	51%	11005	13%	11,276	11%
	A3	8.7	50	14,455	433,637		44%	8,083	44%	12774	12%	13,045	10%
	A4	9.5	50	15,848	475,433		40%	9,491	40%	14167	11%	14,438	9%
	A5	16.1	50	26,833	805,000		34%	17,566	35%	24,040	10%	24,693	8%
	A6	24.4	50	40,667	1,220,000		41%	25790	37%	36,130	11%	37,307	8%
B	B(tailings1)	1.7	50	2,878	86,347	27	100%	-	-	-	-	-	-
	B(tailings2)	0.6	50	1,050	31,500		100%	-	-	-	-	-	-
	B1	3.6	50	5,950	178,515		66%	2,088	65%	4843	19%	5,225	12%
	B2	4.7	50	7,827	234,817		50%	4,186	47%	6720	14%	7,097	9%
	B3	1.4	50	2,397	71,900		0%	2,387	0%	2392	0%	2,397	0%
C	C(tailings)	2.7	50	4,568	137,044	20	100%	-	-	-	-	-	-
	C1	5	50	8,254	247,620		55%	3,350	59%	6532	21%	7,044	15%
	C2	6.1	50	10,113	303,391		45%	5,235	48%	8370	17%	8,893	12%
	C3	7.4	50	12,380	371,400		37%	7,502	39%	10637	14%	11,160	10%

(a) Reduction in flow along the main stem of the stream at the downstream end of the reach.

Reductions in long-term post-closure streamflows vary by location, and typically range from 3 to 5% for average conditions and from 8 to 15% for dry month conditions. Reductions are slightly greater in the shorter term post closure (e.g., Year 42 when interceptor pumping ends) at 4 to 7% and 10 to 21% for average and dry conditions, respectively. Flow reductions typically decrease with increasing distance downstream. The exception of Basin A6, with a slight increase compared to Basin A5, is a result of tributary flow from Basin B. The reductions in flows for long-term post-closure conditions reflect decreased infiltration rates through the tailings, and the resulting reduction in groundwater movement to downstream areas.

Changes in flow areas, water depths and velocities were estimated at the three hydrometric monitoring locations based on expected changes in flows. A summary of the changes is presented in Tables 3.8-9 and 3.8-10. During operation, the estimated 30 to 40% reductions in flow would result in 5 to 31% reductions in both flow area and average depth. Estimated flow velocity reductions are 15 to 33%, although the changes are only 0.1 to 0.2 m/s in terms of magnitude. For post-closure conditions the reductions in flow are relatively small, resulting in negligible changes in hydraulic characteristics for both operations (0 to 6%) and post-closure (0 to 4%).

As described previously, operation of the tailings facility will divert flow from the upper watersheds of the tailings basins and has also been designed to contain the 1:50 year 24-hour storm (402 mm of precipitation). As a result of diversions to the water pond, peak flows and water levels in Basin A and C downstream of the embankments will be reduced compared to baseline conditions. Peak flows and water levels will also be reduced in Basin B where, for storms up to the 1:50 year event, all runoff is held in the water pond and subsequently discharged to the ocean. For larger events, the facility will still contain the volume associated with the 1:50 year storm, and runoff in excess of this volume will be released to the downstream area of Basin B. Excess runoff volumes will be considerably less than if no storage was provided, therefore, peak flows and water levels for this scenario will also be reduced compared to baseline conditions. For example, the total precipitation associated with the 1:100 year 24-hour event is 465 mm; however, the tailings facility provides storage for approximately 400mm of rainfall which means only about 65 mm contributes the downstream peak flows. Peak flows and water levels following closure of the tailings facility are expected to be similar to baseline conditions once drainage paths are returned to their natural receiving waterbodies.

3.8.5.6 Results for Key Question H-2: What Effect Will the Tailings Facility Have on Sediment Levels in Water Bodies?

Erosion is the action of precipitation and surface water flow dislodging and removing soil from ground surfaces, leading to suspension and transport of the soil particles by surface waters. Erosion may occur in the terrestrial (uplands) portion of the watershed, or in the stream channel itself. Sedimentation is the downstream deposition of these eroded soil particles when the surface waters slow and drop the suspended soil particles. Disturbance of vegetation and soil structure due to project activities has the potential to increase erosion, sediment levels in receiving water bodies, and downstream sedimentation.

Generally, soil erosion is expected to increase during facility construction activities, primarily due to removal of vegetation. Sediment control measures are proposed for the tailings impoundment embankment to minimize erosion (refer to Volume C, Section 3.8 for examples). It is expected that impacts due to erosion and subsequent sedimentation from the tailings impoundment embankment will be low.

Table 3.8-9 Estimated Changes in Flow Characteristics[a] – Operation

Scenario	Sub-Basin	Station	Baseline					Operations					Operations- Percentage Change				
			Flow (m^3/s)	Flow Area (m^2)	Average Depth (m)	Max Depth (m)	Average Velocity (m/s)	Flow (m^3/s)	Flow Area (m^2)	Average Depth (m)	Max Depth (m)	Average Velocity (m/s)	Flow (m^3/s)	Flow Area (m^2)	Average Depth (m)	Max Depth (m)	Average Velocity (m/s)
average month	A4	QESF-203	0.52	7.4	0.9	1.24	0.07	0.31	5.5	0.67	1.05	0.06	-40%	-26%	-26%	-15%	-14%
	A5	QESF-207	0.88	11.9	1.7	2.58	0.07	0.58	11.2	1.59	2.47	0.05	-34%	-6%	-6%	-4%	-29%
	A6	QESF-201	1.34	14.3	0.64	1.3	0.09	0.79	9.8	0.44	1.10	0.08	-41%	-31%	-31%	-15%	-15%
dry month	A4	QESF-203	0.18	4.4	0.54	0.94	0.04	0.11	4	0.49	0.88	0.03	-39%	-9%	-9%	-6%	-25%
	A5	QESF-207	0.31	10.2	1.45	2.33	0.03	0.21	9.7	1.38	2.26	0.02	-32%	-5%	-5%	-3%	-33%
	A6	QESF-201	0.47	6.3	0.49	0.92	0.07	0.28	4.8	0.37	0.80	0.06	-40%	-24%	-25%	-13%	-19%

[a] Flow characteristics at hydrometric monitoring locations (located at bridge crossings).

Table 3.8-10 Estimated Changes in Flow Characteristics[a] – Post-Closure

Scenario	Sub-Basin	Station	Baseline					Post-Closure					Post-Closure - Percentage Change				
			Flow (m^3/s)	Flow Area (m^2)	Average Depth (m)	Max Depth (m)	Average Velocity (m/s)	Flow (m^3/s)	Flow Area (m^2)	Average Depth (m)	Max Depth (m)	Average Velocity (m/s)	Flow (m^3/s)	Flow Area (m^2)	Average Depth (m)	Max Depth (m)	Average Velocity (m/s)
average month	A4	QESF-203	0.52	7.4	0.9	1.24	0.07	0.5	7.2	0.88	1.22	0.07	-4%	-3%	-2%	-2%	0%
	A5	QESF-207	0.88	11.9	1.7	2.58	0.07	0.87	11.9	1.7	2.58	0.07	-1%	0%	0%	0%	0%
	A6	QESF-201	1.34	14.3	0.64	1.3	0.09	1.32	14	0.63	1.29	0.09	-1%	-2%	-1%	-1%	-4%
dry month	A4	QESF-203	0.18	4.4	0.54	0.94	0.04	0.17	4.4	0.53	0.93	0.04	-6%	0%	-2%	-1%	0%
	A5	QESF-207	0.31	10.2	1.45	2.33	0.03	0.3	10.1	1.44	2.32	0.03	-3%	-1%	-1%	0%	0%
	A6	QESF-201	0.47	6.3	0.49	0.92	0.07	0.46	6.1	0.48	0.91	0.07	-2%	-4%	-2%	-1%	-6%

[a] Flow characteristics at hydrometric monitoring locations (located at bridge crossings.

Erosion that occurs within the tailings impoundment will be contained within the pond for all events up to the 1:50 year design storm. Flows in excess of the 1:50 year storm will discharge to the environment; however, the water ponds will still act as sedimentation basins and will help reduce sediment concentrations to receiving streams. The discharges will mix with downstream water from undisturbed basins that will also be high in sediment due to the naturally high erosion rates associated with these types of rainfall and runoff conditions.

During construction there will be a temporary increase in sediment derived from the outer surfaces of the newly constructed tailings embankment, before revegetation and stabilization of the embankment. New construction phases will occur throughout the life of the project as new embankments are built to contain the tailings. Mitigations to minimize the amount of sediment transported off-site and protect water quality will include sediment control structures, a storm water management system, best management practices and reclamation measures.

Closure of the tailings impoundment will entail construction of permanent spillways that are designed to resist erosion and that will convey water to natural streams. These spillways will have mild channel slopes to minimize the possibility of erosion. Closure plans also call for revegetation or alternate erosion control of the final tailings surfaces.

3.8.6 Impact Analysis

3.8.6.1 Residual Impacts

Residual impacts associated with hydrology are shown in Table 3.8-11. Results of the impact analysis indicate that, during operation, streamflows downstream of the tailings embankment will be reduced considerably due to the runoff diversion in the upper basin and the resulting reduction in drainage area at downstream locations. The expected changes along the main stems of the rivers are considered high in magnitude (greater than 30%) in all basins except Basin B3, which is not affected by the development. Other upper tributary areas, including a large portion of Basin C1, are also unaffected by the diversion. The high magnitude impact extends to the boundary of the local study area to where a large tributary river joins the Ambolona River system.

Based on the high magnitude effect, local extent, and medium-term duration, the environmental consequence during operation is considered high. This classification relates to changes in stream hydrology, however, endpoints for other biophysical or social disciplines are assessed separately. A high consequence in terms of hydrology does not necessarily equate to a high consequence for water quality, fish and aquatic resources, agriculture/land use or social components.

Changes in streamflows for post-closure conditions are negligible to low for average conditions, therefore the environmental consequence is considered low. For dry months, moderate changes in stream flows may occur, however, due to the medium-term duration, the resulting environmental consequence is also considered low.

Changes in water levels have not been assessed explicitly within the three tailings valleys. Along the main stem of the Ambolona River, however, changes in maximum depth are expected to be low to moderate at three specific locations. The effects are expected to be confined to the local study area during operation. Site-specific information along other reaches of the streams are not available for further evaluation. Based on the above discussion, however, the resulting environmental consequence is expected to be low.

Changes in sediment levels are expected to be high during construction as land is cleared and construction activities lead to soil disturbance and erosion. With the implementation of mitigations and erosion control, the extent of impact is expected to remain local and be of relatively short duration. Once embankment slopes are reclaimed, sediment generation and transport to downstream locations will be greatly reduced. Active sediment control will continue throughout operations and will contribute to a low environmental consequence. At closure, runoff will be directed to their natural receiving water bodies and return to pre-development conditions. An initial flush of sediments may occur immediately following closure due to higher flows that are generated by the larger drainage areas which are re-established as part of the closure plan.

Table 3.8-11 Residual Impact Classification for Hydrology

Phase	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Issue: Changes in Streamflows and Water Levels in Receiving Water Bodies							
construction/ operations	negative	high	local	medium-term	yes	high (average conditions)	high
closure	negative	**average conditions:** negligible to low **dry month conditions:** moderate for main valleys and negligible along the main stem of the ambolona river	local	long-term	no	high (average conditions)	**average conditions:** low **dry month conditions:** low
Issue: Changes in Sediment Levels in Receiving Water Bodies							
construction	negative	high	local	short-term	yes	high (average conditions)	moderate
operations	negative	low to moderate	local	medium-term	yes	high (average conditions)	low
closure	negative	negligible to low	local	long-term	no	high (average conditions)	low

3.8.6.2 Prediction Confidence

With the exception of evapotranspiration, the primary climate variables affecting baseline hydrology are well understood. Hydrology in terms of rainfall response and runoff generation is understood to the extent of the limited amount of site-specific data that are available. Similarly, the interaction between surface water and groundwater in the project area is difficult to quantify, particularly during the dry season in locations where surface flows may be dominated by groundwater inflows.

The impact ratings are based on a hydrologic model that assesses average monthly conditions based on a reasonable estimate of annual rainfall and runoff. For these average conditions, the prediction confidence is considered medium. For dry monthly conditions, however, flow estimates are based on a runoff depth derived from a single dry season of hydrometric monitoring and the estimated interaction with groundwater. Based on the uncertainties associated with these parameters, the prediction confidence for dry season conditions is considered low.

3.8.6.3 Monitoring

Continued monitoring of streamflows and suspended sediment concentrations within the affected basins will be conducted to support an improved understanding of hydrologic response in the study area. Streamflow records will be evaluated along with recorded climate data (e.g., rainfall and evaporation) at nearby Toamasina to further assess water availability for various biophysical and social needs.

Monitoring of the effectiveness of erosion control measures, slope stability and reclamation success are described in Volume C, Section 6.

3.8.7 Conclusions

During operation, the tailings facility will have a high environmental consequence for hydrology in terms of streamflows at downstream locations. Following closure and the return of runoff to natural receiving water bodies, the environmental consequence for most locations will be negligible to low for average conditions, and low for dry conditions. While impacts to hydrology are considered large, the impact of these changes to associated components (e.g., water quality, fish and aquatic resources, and land use and socioeconomics) is variable. These issues are addressed in other sections of this report. Downstream flooding associated with extreme rainfall events (e.g., the maximum probable precipitation event, and breach of the water pond embankment) is also discussed in the Natural Risk assessment (Volume E, Section 3.6, and Volume I Section 6.1).

3.9 OCEANOGRAPHY

3.9.1 Introduction

This assessment provides impact analyses relating to the biological, physical and social environments at the site of the marine outfall from the tailings facility. This assessment was conducted for the proponent by Coastal & Environmental Services (CES) of South Africa. Baseline conditions are described in Volume J, Appendix 10.1, Attachment 2.

3.9.2 Methods

3.9.2.1 The Impact Evaluation Criteria

The rating system used for assessing issues in this study is primarily based on three criteria, namely:

- the relationship of the issue to temporal scales (Box 1);
- the relationship of the issue to spatial scales (Box 2); and
- the severity of the issue (Box 3).

These three criteria are combined to describe the overall importance rating, namely the environmental consequence (Box 4). In addition, the following parameters are used to describe the issues:

- the risk or likelihood of the issue occurring (Box 5); and
- the degree of confidence placed in the assessment of the issue (Box 6).

TEMPORAL SCALE

The temporal scale allows assessment of impact at various time scales.

Box 1: Temporal scale used in the EIA.

Short term	Less than 5 years. Many construction phase impacts will be of a short duration.
Medium term	Between 5 and 20 years.
Long term	Between 20 and 40 years (a generation) and from a human perspective, essentially permanent.
Permanent	Over 40 years and resulting in a permanent and lasting change.

SPATIAL SCALE

The spatial scale defines physical extent of the impact.

Box 2: Spatial scales used in assessing issues.

Household	This scale applies to households in the affected area.
Localised	A few hectares in extent, including port and immediate surrounds.
District	Toamasina Province.
Regional	Toamasina Province as well.
National	Madagascar.
International	International.

MAGNITUDE RATING SCALE

The magnitude scale was used to evaluate how severe negative or beneficial positive impacts would be, on a particular affected system (for ecological impacts) or a particular affected party. It is a methodology that attempts to remove any value judgments from the assessment, although it relies on the professional judgment of the specialist.

Box 3: Magnitude (can be negative or positive)

Very Severe	A >30% change in aspect affected.
Severe	A 10-30% change in aspect affected.
Moderately Severe	A 5-10% change in aspect affected.
Slight	A <5% change in aspect affected.
No Effect	No measurable change.

ENVIRONMENTAL CONSEQUENCE SCALE

The environmental consequence scale is an attempt to evaluate the importance of a particular impact. This evaluation needs to be undertaken in the relevant context, as an impact can either be ecological, social or both. The evaluation of the environmental consequence of an impact relies heavily on the values of the person making the judgment. For this reason impacts, especially of a social nature need to reflect the values of the affected society as well as consider the individual impact criteria ratings. A six-point Environmental Consequence scale has been applied (see Box 4).

In many cases scientists have to produce an assessment in the absence of all the relevant and necessary data. American legislation (Section 40, Code of Federal

Regulations (CFR) 1502.22) has considered these limitations, and makes the following recommendations:

"When an agency is evaluating reasonably foreseeable significant adverse effects on the human environment in an Environmental Impact Statement (EIS) and there is incomplete or unavailable information, the agency shall always make clear that such information is lacking if the incomplete information is essential to a reasoned choice among alternatives. If the overall costs of obtaining it are not exorbitant, the agency shall include the information in the EIS".

There are two acceptable procedures to follow to compensate for a shortage of data:

1. It is more important to identify likely environmental impacts than to precisely evaluate the more obvious impacts.

All assessors (the different specialists) try to evaluate all the largest impacts, recognising that precise evaluation is not possible. It is better to have a possible or unsure level of certainty on important issues than to be definite about unimportant issues.

2. It is important to be conservative when reporting likely environmental impacts.

Because of the fact that assessing impacts with a lack of data is more dependent on one's own scientific judgment, the rating on the certainty scale cannot be too high. If the evidence for a potential type of impact is not definitive in either direction, the conservative conclusion is that the impact cannot be ruled out with confidence, not that the impact is not proven. It is for these reasons that a degree of certainty scale has been provided, as well as the category Don't Know.

Box 4: The Environmental Consequence Rating Scale

VERY HIGH

These impacts would be considered by society as constituting a major and usually permanent change to the (natural and/or social) environment, and usually result in severe or very severe effects, or beneficial or very beneficial effects.

HIGH

These impacts will usually result in long term effects on the social and/or natural environment. Impacts rated as high will need to be considered by society as constituting an important and usually long term change to the (natural and/or social) environment. Society would probably view these impacts in a serious light.

MODERATE

These impacts will usually result in medium to long term effects on the social and/or natural environment. Impacts rated as moderate will need to be considered by society as constituting a fairly important and usually medium term change to the (natural and/or social) environment.

LOW

These impacts will usually result in medium to short term effects on the social and/or natural environment. Impacts rated as low will need to be considered by the public and/or the specialist as constituting a fairly unimportant and usually short term change to the (natural and/or social) environment. These impacts are not substantial and are likely to have little real effect.

NO IMPACT

There are no primary or secondary effects at all that are important to scientists or the public.

DON'T KNOW

In certain cases it may not be possible to determine the environmental consequence of an impact.

RISK OR LIKELIHOOD SCALE

The risk or likelihood of an impact taking place as a result of project actions varies. There is no doubt that some impacts would occur if the outfall goes ahead, but certain other (usually secondary) impacts are not as likely, and may or may not result from the outfall. Although these impacts may be severe, the likelihood of them occurring may affect their overall environmental consequence and will be taken into account.

Box 5: The Risk or Likelihood Scale

Very unlikely to occur	The chance of these impacts occurring is extremely slim, e.g., an earthquake destroying back-of-port area.
Unlikely to occur	The risk of these impacts occurring is slight, but impacts such as a catastrophic shipping accident may occur.
May occur	The risk of these impacts is more likely, although not definite, for example the disturbance of the reef environments.
Will definitely occur	There is no chance that this impact will not occur, minor oil spills during refuelling.

DEGREE OF CERTAINTY OR CONFIDENCE

It is also necessary to state the degree of certainty or confidence with which one has predicted the environmental consequence of an impact. For this reason, a 'degree of certainty' scale has been provided to describe how certain we are of our assessment.

Box 6: The Degree of Certainty or Confidence Used in This Study

Definite	More than 90% sure of a particular fact. To use this, one will need to have substantial supportive data.
Probable:	Over 70% sure of a particular fact or the likelihood of that impact occurring.
Possible	Only over 40% sure of a particular fact or of the likelihood of an impact occurring.
Unsure	Less than 40% sure of a particular fact or the likelihood of an impact occurring.

3.9.3 Marine Outfall Assessment – Physico-Chemical Composition and Possible Impacts

3.9.3.1 INTRODUCTION

A large body of information exists on the approximately 1,500 known chemical compounds and elements, which could act as pollutants in the marine environment (USEPA, 2004). The impacts of these on individual organisms depend on a number of factors, which can alter the inherent character of the chemicals in question. These factors could be as simplistic as a change to ambient temperature or a change in the pH of the water. Additional factors include individual organism's range of tolerance to these changes, the concentration of the pollutant and the time of exposure to it. In addition, the impact of pollution may not affect the organism or community directly but is dependent on the pollutants fate within the aquatic environment (Figure 3.9-1). For example, a chemical constituent such as zinc, an important micronutrient in plants, does not present a threat to these primary producers. The algae, however, absorb this element and through a process of bio-accumulation can become toxic at a higher trophic level (Figure 3.9-1). For example, predatory fish that prey on herbivorous fish accumulate the zinc in their livers or kidneys. The concentrations of zinc in their organs then affect the fish's fitness and ability to reproduce. A decrease in reproductive rates then lowers abundance in a particular population and in turn affects community structure (Figure 3.9-1). A community response over time to a pollutant may change its trophic structure (reduction of predators), which results in an overall increase in the amount of grazers. The high numbers of grazers places pressure on the primary producers, leading to an overall reduction in food resources. This results in a reduction in biodiversity and a degradation of the environment.

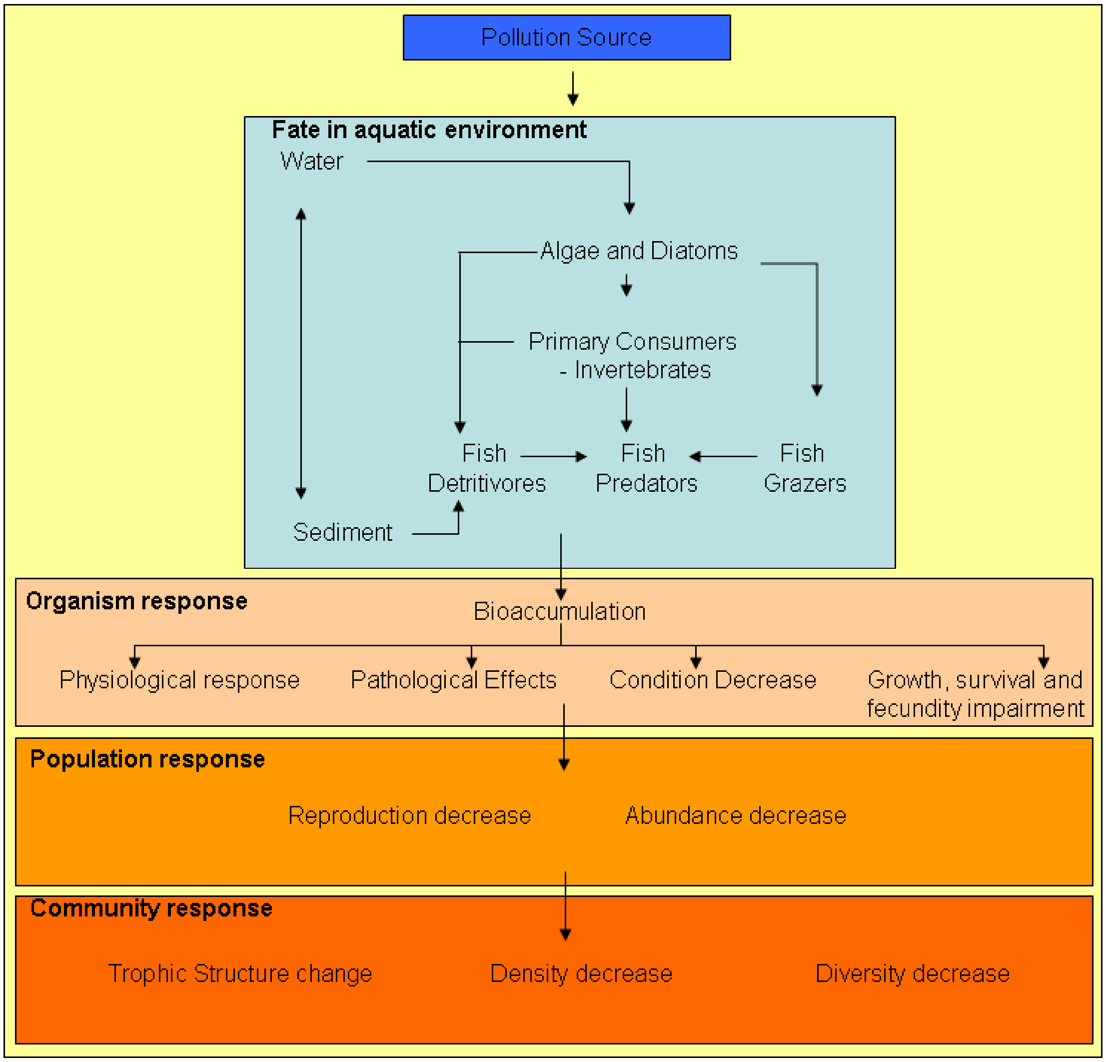


Figure 3.9-1 A diagrammatic description of a pollutant source and its fate within the aquatic environment and the consequent bio-accumulation process.

3.9.3.2 Outfall Character and the Marine Environment

The proposed outfall effluent consists of numerous elements, naturally occurring in seawater (Table 3.9-1). The PRDW dilution and settling modelling (see Volume J, Appendix 10.1, Attachment 2) of the effluent, indicated that total suspended solids (TSS), manganese and sulphate ($S(SO_4)$) were the only constituents which would be well above natural levels or the Malagasy water quality standards (Table 3.9-1). These in particular would require further dilution on disposal into the marine environment in order to reduce the possible negative impacts of these constituents. In addition, the effluent is buoyant and will move towards the surface reducing the impacts on the fauna in deeper areas. However, if the effluent is not sufficiently diluted and accumulates in the upper water column, impacts of reduced sunlight penetration may result.

A summary of the constituents which could impact the marine environment is presented in this section. Consideration is given to all known variables and constituents of the outfall effluent which pose a risk to the marine environment. Detailed consideration of TSS, manganese and sulphate is presented towards the end of this section. Table 3.9-1 further summarizes the possible impact of the outfall on the three main trophic levels, which are used as indictors of polluted marine systems in international literature. The response of the organisms or trophic levels can then be used in describing guideline values for proactive long-term monitoring of the environment as part of the project (Table 3.9-2).

LIMTITATIONS

The Flemish Institute for Technological Research (VITO) has dealt with marine environmental toxicology for a number of years. Research from this institute has shown that the ability of a risk assessment to assess contaminant cause-and-effect relationships in the environment (water and sediments) are hampered by changes in ambient conditions. In ecotoxicological research, biotic responses are related to quantitative contaminant concentrations, which in most cases are still expressed in terms of "total elemental concentration" and not in terms of "elemental species." However, it becomes evident that the abundance and distribution of pollutants in the environment, their bio-availability, and their toxicity to aquatic organisms (including humans) can often be better understood in terms of "elemental species." The persistence, mobility, chemical reactivity, sorption dynamics, of contaminants in water are governed by a range of changing physicochemical parameters (pH, temperature, organic matter, suspended solids, etc.), which dictate the effects at the organism level. Studies on the assessment of the impact of changing physico-chemical parameters on the chemical speciation of pollutants, which finally determine toxicity and bio-accumulation in organisms, deserve more attention in environmental toxicology (VITO, 2005).

It is thus important to know that the following assessment has been based on the information available using general guidelines based on total elemental concentrations shown in Table 3.9-1. The synopsis presented below is based on estimations of the present water quality based on published literature and the quality of the effluent. Due consideration of the actual affects can only be established once the baseline variability of the region's water quality is better understood. The actual reactions of the effluent once admitted to the environment can then be established. However, for this report, this not a significant concern because the majority of the constituents which could be extremely toxic occur at low levels. The proponent, aided by Aquaterre have established a baseline water monitoring programme, with monitoring sites being selected to coincide with the CES and Oceanographic Research Institute (ORI) dive sites. This will establish present and future biological responses to changing water quality conditions and aid in the better understanding of the possible impact of the marine outfall. Constituents of concern for which limited information was available and would need consideration include elements such as cobalt.

Description Of Possible Chemical Influences Of The Outfall On The Biota

Change In Ambient Temperature

Although the temperature of the proposed outfall approximates the ambient ocean temperature (25°C) of the region (Volume I, Appendix 10.2, Attachment 2) the constant temperature of the outfall does not represent seasonal temperature variations, which may exist. Invertebrates are the most susceptible to the effects of constant temperature regimes. Noticeable effects are the physiological and reproductive responses of bivalves. Bivalve reproduction cycles are triggered by changes in ambient temperature, related to seasonal differences. Physiological responses include losing the ability of movement, which is also observed in anemones, mostly due to the denaturation of body tissue in both groups (Inchem, 2005).

Mobile adult species, such as fish and crustaceans, are least sensitive to temperature variation as these species will move to suitable environs or become tolerant of the adjusted temperature over time. Growth and reproductive success could be affected in these groups, both having a reduction in the number of viable eggs and changes in growth rates. In the case of crustaceans, increased temperatures result in stunted growth rates (Inchem, 2005).

Table 3.9-1 Suggested target values for the natural marine environment, which should be used as a monitoring guideline.

Parameter	Recommended target values within acceptable variations	Unit	Effluent to Ocean Worst Case	Seawater Compo-sition 1	Malagasy Limit 2	World Bank General 1998	Primary Producers	Primary Consumers	Secondary Consumers
pH	7.3 – 8.5		7 - 8		6 - 9	6 - 9		X	
Conductivity	200	uS/cm			200				
Hardness	-				180				
Temperature	+ or – 10C	0C	25		30				
TSS	Not increase by 10% above ambient conditions	mg/L	100		60	50	X		
Salinty	33 -36	ppt	-	35	-	-	X	X	
Al	5	mg/L	<0.002	0.001	5			X	X
Sb	-	mg/L	<0.004	0.00033					
As	0.036	mg/L	<0.0005	0.0026	0.5	0.1	X	X	
Ba	100 – 550 ug/L – Mussel embryos	mg/L	0.0025	0.021				X	
Be	-	mg/L	<0.0025	0.0000006					
Bi	-	mg/L	<0.0025	0.00002					
B	-	mg/L	<0.0025	4.45					
Cd	0.01	mg/L	<0.0005	0.00011	0.02	0.1		X	X
Ca	-	mg/L	225	411					
Cl	-	mg/L	6	19400					
Co	?	mg/L	0.03	0.00039					
Cu	0.05	mg/L	0.0045	0.0009		0.5	X	X	
CrT	0.08	mg/L	0.005	0.0002	2	0.5		X	X
F	-	mg/L	0.5	13		20			
Fe	10	mg/L	<0.0015	0.0034	10	3.5			
Pb	0.1	mg/L	<0.0025	0.00003	0.2	0.1	X	X	X
Li	-	mg/L	<0.0025	0.17					
Mg		mg/L	1025	1290					
Mn	-	mg/L	115	0.0004	5				
Hg	0.0025	mg/L	<0.0005	0.00015	0.005	0.01	X	X	X
Mo	-	mg/L	0.001	0.01					
Ni	0.25	mg/L	0.0415	0.0066	2	0.5		X	X
P	0.0001 – 0.001	mg/L	<0.015	0.088		2			
K	-	mg/L	0.215	392					
Sc	-	mg/L	5	<0.000004					
Se	0.007	mg/L	0.005		0.02	0.1		X	X
Na	-	mg/L	2.5	10800					
Si	-	mg/L	0.25	2.9					
SO4		mg/L	4750	--	250				
Te	-	mg/L	<0.05	--					
Th	-	mg/L							
V	0.001	mg/L	<0.001	0.0019					
Zn	0.25	mg/L	<0.001	0.005	0.5	2			

[a] The table also indicates the trophic level most affected by changes in a particular constituent thus suitable as a monitoring indicator.

Changes in Salinity

Salinity refers to the dissolved salt content of seawater, to which marine organisms have developed osmotic control mechanisms (exclusion or excretion) of ionic salts. The average salinity of most oceans has been estimated at between 34 - 35 ppt (parts per thousand), with most marine organisms being able to tolerate variations any where between 33 and 36 ppt. Tropical regions are known to experience higher evaporation rates and thus higher average salinities of 35 ppt are expected (DWAF, 1995).

Primary producers such as green algae (e.g. *Ulva* spp.) are the most susceptible to decreases in salinity, with sudden mass mortalities usually a result. Brown and red algae are able to tolerate gradual declines in salinities, down to 15 ppt for short periods of time, resulting in limited osmotic damage (DWAF, 1995).

Primary consumers are less susceptible to changes in salinity, with most literature indicating that prawns and shrimp are most likely to experience osmotic stress (Inchem, 2005). Sudden changes to ambient salinity constantly results in mass mortality within prawn banks, where sudden freshwater inputs are likely, such as in estuaries. Adult fish (primary consumers and secondary consumers) have better physiological control mechanisms for changes in osmotic conditions, either through the exclusion / excretion of ions (increase salinity) or active excretion of water via kidney function (decrease salinity) (Figure 3.9-2). Again the developing eggs, embryos and larvae of these consumers face the greatest risk in terms of salinity changes (DWAF, 1995).

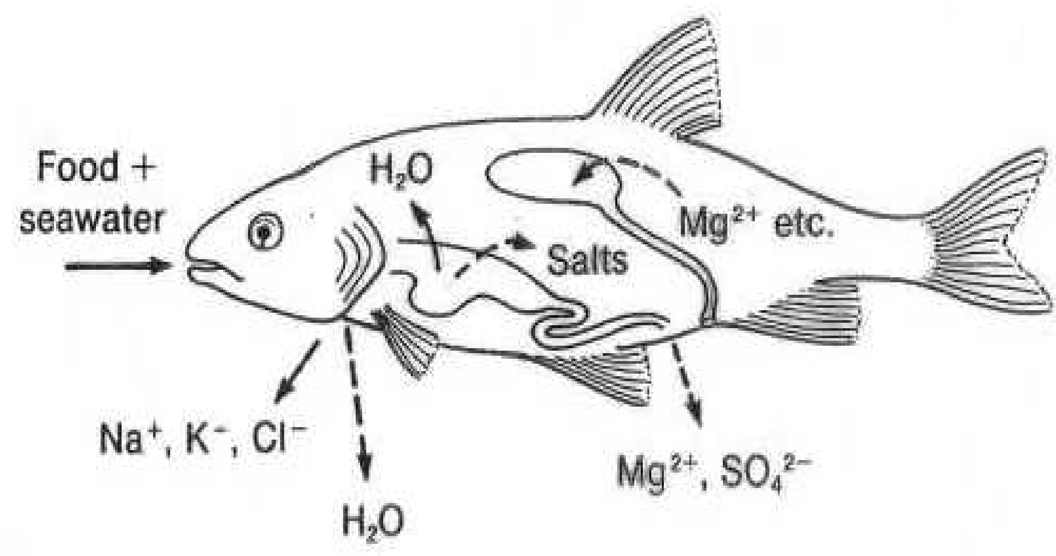


Figure 3.9-2 Salt exclusion mechanisms used by Teleost fish; either by the gills, urinary or digestive systems, adapted from Prosser, 1973.

Changes in pH

Seawater pH remains between 8 and 9, with most guidelines indicating that the acceptable pH variation is between 7.3 and 8.2. It is anticipated that the outfall will be neutralized to a pH of 8 for the duration of the project. Most primary producers find this to be the optimal pH (8) for growth, while primary and secondary consumers find the acceptable range mentioned in the guidelines, adequate for adults, eggs and larvae. The only exception being molluscs, which are shelled organisms, such as mussels, oysters and barnacles. If the seawater pH drops below 8, most of the outer-shells of these species begin to dissolve, making them prone to diseases and predation (DWAF, 1995).

Aluminium

Aluminium is of special concern in terms of elemental speciation, when related to change in pH. High concentrations of aluminium become toxic to aquatic organisms within acidified waters. Aluminium (Al^{3+}) is mobilized into its soluble form ($Al(H_2O)^{3+}$) from sediments, as the pH drops below 4 (Sharma, 2003). However different soluble forms are toxic to aquatic biota and may pass onto the wider food web becoming increasingly toxic to other organisms through bio-accumulation and biomagnification processes. The most toxic forms of aluminium are known to be aqueous hydroxo-Al species [Al^{3+}, $AlOH^{2+}$ and $Al(OH)^{2+}$], but the complex forming agents like organic acids and fluorides (Al-Org and Al-F) bind with the toxic forms reducing the overall toxicity (Sharma, 2003).

The gills, skeleton, kidney, liver and muscles are the main target organs for aluminium toxicity. Organisms respond immediately with respiratory, kidney and liver dysfunction, followed by growth defects affecting the skeleton. Though the relationship between aluminium and toxicity is well understood, the mechanisms through which aluminium exerts its toxic properties needs more research (Inchem, 2005). Acid neutralising of the outfall effluent would thus be of utmost importance and the addition of lime (basic) being a suggested means of reducing Al toxicity (Sharma, 2003). The average concentration of aluminium in seawater is approximately 0.001 mg/L. The outfall aluminum concentration would approximate this concentration (<0.002) and is well below the Malagasy limit of 5 mg/L, thus posing no risk to the marine environment. The Malagasy limit has thus been prescribed for future monitoring.

Arsenic

Arsenic is a metalloid (metal like properties), which can be found naturally on earth in small concentrations. It occurs in soil and minerals and it may enter air and water through wind-blown dust and surface water run-off (Allen, 2005).

Arsenic does not easily convert to water-soluble or volatile products. Arsenic is naturally a mobile element, which indicates that large concentrations are not likely to appear in one specific site (Inchem, 2005).

Plants readily absorb arsenic, acting as bio-concentrators. This exposes primary consumers to the risk of genetic defects over time, while secondary consumers may be at risk of nervous tissue damage and possible death if large amounts of the prey are consumed (Allen, 2005). Most algae grow normally in arsenic concentrations between 0.19 and 100 mg/L, however repeated exposures to concentrations greater than 0.19 mg/L reduces reproductive fitness of the plants and viability of reproductive spores. This is similarly evidenced in the primary consumers, however, prolonged exposures results in 50% mortality in all mollusc species studied after 96 hours of exposure (DWAF, 1995). Within the secondary consumers, polychaete worms, copepods and mysids are tolerant of high arsenic levels up to 500 mg/L. Vertebrates however, experience high mortalities at concentrations as low as 7 mg/L when exposed for more than 96 hours. Further exposure results in growth abnormalities over time (DWAF, 1995). In determining monitoring guidelines, the majority of international limits vary. Although the arsenic concentration (<0.0005) within the outfall is lower than any guideline and the natural composition of seawater (0.0026). It is therefore recommended that the lower USEPA precautionary guideline of 0.036 mg/L be used.

Cadmium

Cadmium can mainly be found in the earth's crust. It always occurs in combination with zinc. Cadmium mainly affects primary and secondary consumers, with no known symptoms exhibited by plants (DWAF, 1995). In aquatic ecosystems cadmium can bio-accumulate in mussels, oysters, shrimp, lobsters and fish. The susceptibility to cadmium can vary greatly between aquatic organisms. Marine organisms are known to be more resistant to cadmium poisoning than freshwater organisms (Inchem, 2005). In higher organisms, cadmium is first transported to the liver via the blood, where it is bound to protein complexes and transported to the kidneys. Cadmium accumulates in kidneys, where it damages filtering mechanisms. This causes the excretion of essential proteins and sugars from the body and further kidney damage (DWAF, 1995). The majority of LC_{50} studies indicated that cadmium, becomes detrimental to organisms' health at concentrations of between 0.001 and 0.004 mg/L, indicated by physical stress (respiratory and kidney dysfunction) and later death after 96 hours of exposure in most test cases (DWAF, 1995). A monitoring guideline of 0.01 mg/L is therefore recommended. The outfall has been estimated at <0.0005 mg/L, which is well below any guideline, and thus safe to the marine environment.

Chromium

The health hazards associated with exposure to chromium are dependent on its oxidation state. There are several different kinds of chromium that differ in their effects upon organisms. Chromium enters the air, water and sediments in the trivalent chromium (III) and hexavalent chromium (VI) forms both through natural processes and anthropogenic activities (Allen, 2005).

The metal form (chromium as it exists in the effluent) has a low toxicity. The hexavalent chromium form is highly toxic. Chromium and most trivalent chromium compounds have been listed by the National Toxicology Program (NTP) as having inadequate evidence for carcinogenic properties in experimental animals (Inchem, 2005).

Chromium is not known to accumulate in the bodies of fish, but high concentrations of chromium, due to the disposal of metal products in waters, can damage the fish gills occupying areas near the point of disposal. Chromium can cause respiratory problems, decreased immune responses, birth defects, infertility and tumor formation. The effect on primary producers is not known, but concentrations between 0.008 and 2 mg/L do impact on the high trophic levels (DWAF, 1995). The outfall effluent would be well below this with an anticipated concentration of 0.005 mg/L.

Copper

Copper also occurs naturally in the environment and spreads through the environment through natural phenomena. Examples of natural sources are wind-blown dust, decaying vegetation, forest fires and sea spray (Allen, 2005).

When copper settles out within sediment it strongly bonds with organic matter and minerals. Copper, however, does not break down readily in the environment and thus accumulate in plants and animals. A high concentration of copper in the aquatic environment inhibits growth and sporophyte production in algae. While there is a sufficient body of literature, which indicates that a higher number of primary and secondary consumers experience loss of muscle movement at low exposures or mortality at higher exposures (> 0.05 mg/L) for extended periods, i.e. > 96 hours (DWAF, 1995). A monitoring guideline limit of 0.05 mg/L is thus advised. Copper within the outfall, will only reach levels of 0.0045 mg/L.

Lead

Lead is a bluish-white lustrous metal. Most lead concentrations found in the environment are a result of human activities. The application of lead in fuels has resulted in an unnatural lead-cycle.

Lead bio-accumulates in the bodies of both benthic and planktonic organisms, including phytoplankton. Lead rapidly interferes with physiological process, inhibiting growth and reproductive vigour by a reduction in enzyme activity (DWAF, 1995). All levels of organisms show signs of impacted health, when lead levels reach 0.1 mg/L. It is therefore recommended that this level be used as the recommended monitoring guideline limit, which is below the outfall level of <0.0025 mg/L.

Mercury

Mercury is the only common metal, which is liquid at room temperatures. It rarely occurs free in nature and often occurs as a salt. The most important mercury salts are mercuric chloride $HgCl_2$ (corrosive and extremely poisonous), mercurous chloride Hg_2Cl_2 (Calomel, still used in medicine occasionally), mercury fulminate ($Hg(ONC)_2$, a detonator used in explosives) and mercuric sulphide (HgS, Vermillion, a high-grade paint pigment).

Acidic waters can contain significant amounts of mercury. When pH values are between 5 and 7, mercury is readily mobilized from sediments and microbes convert it to methyl mercury, a substance that is quickly absorbed by most organisms and a known cause of nerve damage. Fish easily absorb large amounts of methyl mercury, which accumulate in the major organs (WHO, 2004). This results in kidneys damage, stomach disruption, damage to intestines, reproductive failure and genetic alteration (Allen, 2005).

Tolerance levels for all trophic levels are low with most acute effects within organisms being prevalent at levels mercury of between 0.003 and 0.1 mg/L (WHO, 2004; DWAF, 1995). A guideline level of 0.0025 mg/L is advised for mercury. Expected outfall levels would this not be a risk at <0.0005 mg/L.

Nickel

Nickel occurs combined with sulphur in millerite, with arsenic in the mineral niccolite, and arsenic and sulphur in nickel glance. The greater proportion of all nickel compounds, which are released into the environment will adsorb to sediment particles and become immobile as a result. If these sediments become acidified, nickel will become mobilized. Little information exists on the effects of nickel upon organisms but a high nickel concentration in aquatic systems reduces algal growth rates (Inchem, 2005). Microbes also experience reduced growth rates in the presence of nickel, after which they have the ability to become tolerant.

Nickel is an essential element for vertebrates, but rapidly becomes toxic when the maximum acceptable limits are exceeded. Various cancers and tumours have been attributed to long-term over exposure, however nickel is not known to bio-accumulate in plants or animals. Nickel will thus, not bio-magnify in the food chain. Limited information exists on tolerance levels of marine species, but most international guidelines note the acceptable limit to be less than 0.25 mg/L for marine waters, while the outfall nickel concentration would be expected to be safe at <0.0415 mg/L.

Selenium

Selenium is fairly immobile in anoxic sediments and will not dissolve in water posing no threat to organisms. If oxygen levels and the acidity of the sediments increase, selenium is freed. The behaviour of selenium then strongly depends upon its interactions with other compounds based on environmental conditions (Inchem, 2005). There is evidence that selenium bio-accumulates within the body tissues and is passed up through the food chain. Usually this bio-magnification of selenium starts when animals eat large quantities of plants. The greatest impact of high selenium levels on organisms is reproductive failure and birth defects (Allen, 2005). Chronic effects are experienced mostly in the consumer levels at concentrations greater 0.1 mg/L for extended periods (USEPA, 2004). The USEPA has thus recommended a precautionary approach that selenium does not exceed a value of 0.007 mg/L, with the outfall being lower at 0.005 mg/L.

Total Suspended Solids and Turbidity

Turbidity is a measure of the attenuation of light in a water column and can be caused by the light absorption properties of the water, plankton, suspended particulate matter and dissolved colour. Turbidity is primarily due to suspended particulate matter (or total suspended solids) (Cole et al. 1999) which can enter the marine environment from a number of sources, namely (Parr et al. 1998):

- soil and land erosion;
- sediment re-suspension (including dredging);
- effluent discharge;
- phytoplankton standing crop; and
- chemical flocculation at the freshwater/saltwater interface in estuaries.

Turbidity is, therefore, generally considered to be equivalent to some measure of the concentration of suspended solids in a water body and provides an idea as to the levels of TSS in a system. Although increases in turbidity are generally non toxic, they can have both direct and indirect impacts on the marine environment. Some of these are discussed below in terms of their potential impacts on the marine fisheries around Toamasina.

Macroalgae and other aquatic plant communities within the subtidal and intertidal region of the coastline provide important habitats and refuges for invertebrate communities (Cole et al. 1999). High turbidity levels have been reported to result in reduced growth rates, standing crop and depth of colonisation of macrophytes (Parr et al. 1998). Such conditions may ultimately lead to the reduced availability of suitable habitat and refuges for the juvenile invertebrate and vertebrate species. Within the Toamasina region, the Ivondro Estuary plays an important role as a nursery area for the commercial prawn stocks. Any impacts affecting the availability and extent of these habitats could have severe environmental and economic implications on the prawn stocks.

Evidence suggests that fish populations may be affected by increases in turbidity as a result of suspended matter. The most severe impacts resulting from increased and high turbidity levels are: reduced food availability, the clogging of gillrakers and gill filaments by particulate matter (Cole et al., 1999) and reduced visibility for visual predators and piscivores (De Robertis et al., 2003). Reduction in phytoplankton biomass may result from reduced light penetration, and availability. Adverse effects on zooplankton may arise due to the physical movement of particulates in the water column (Cole et al., 1999). Reductions in these two components of the marine ecosystem can lead to an overall reduction in the food availability to planktivorous fish. Benthic invertebrate prey organisms may also be influenced by high levels of suspended material as large increases in both organic and inorganic particles can result in overloading the feeding processes, damaging feeding structures or smothering organisms (Cole et al., 1999). Changes in the distribution and abundance of these species as a result of the proposed marine outfall could result in large changes in the distribution and abundance of certain fish species which are important to the local fisheries.

Piscivorous fish have also been shown to be substantially more sensitive to elevated turbidity levels. Past investigations have shown that increases in turbidity levels can result in both a reduction in detection and a reduction in the successful capture of prey species by visual predators (De Robertis et al., 2003). This is largely due to the reduced visibility as a result of suspended material and the visual protection which is therefore awarded to the prey species.

However, the impacts mentioned above are likely to arise only under very high turbidity and suspended material levels. Slight increases in turbidity may have positive effects on the marine ecology; for example slight increases in the suspended solids in the water column may increase the food availability to filter feeders in the area. However, this will largely depend on the quality and composition of the suspended material. Increases in particulates of low nutritional value may require higher energy expenditure for handling the larger numbers of particulates with a low overall energy gain (Cole et al., 1999). In addition to providing increased food sources to filter feeders turbid waters also provide small fish species with improved protection from visual predators due to the reduced visibility and sighting distance.

Manganese

Manganese is an essential nutrient for micro organisms, plants and animals (Underwood, 1977) and is actively assimilated and utilized. It does not occur naturally as a base metal but rather occurs as a component of other minerals including sulphides, oxides, carbonates, silicates, phosphates and borates (NAS, 1973 in WHO, 2004). The major anthropogenic sources of environmental manganese include municipal waste water discharges, sewage sludge, mining and mineral processing (particularly nickel), emissions from alloy, steel and iron production, combustion of fossil fuels, and, on to a lesser extent, emissions from the combustion of fuel additives (WHO, 2004).

Although it is an essential nutrient, it is only required to a certain level known as the deficiency limit, after which point it becomes toxic (WHO, 2004). Manganese deficiencies have been shown to limit marine phytoplankton growth (Huntsman & Sunda, 1980) and aquatic organisms at lower trophic levels have shown significant bio-accumulation or bio-concentration (WHO, 2004). Fish, however, do not appear to accumulate manganese to the same extent (Ichikawa, 1961). The uptake of manganese by aquatic invertebrates and fish increases significantly with increasing temperature (Miller et al. 1980) and decreasing salinity and decreases with pH (Rouleau et al., 1996).

Concentrations of manganese in open seawater range from 0.4 to10 ug/L (USEPA, 1984; Zeri et al. 2000). Several manganese toxicity tests have been undertaken on a range of marine algae and invertebrate species using soluble Mn(II) salts rather than colloidal, particulate, and complexed manganese (WHO 2004). However, the toxicity of metals bound into these forms is assumed to be less than those of aqua-ionic forms (WHO 2004). Although manganese may be less toxic in bound forms, it may increase the toxicity of other metals in these states increasing the complexity for interpretation.

LC_{50} testing is often undertaken at extremely high concentrations of the toxicant in order to induce an observable response, and different authors have used varying exposure periods making direct comparison of results difficult. However, several results of short-term toxicity tests are presented below for informative purposes. Toxicity tests on marine microalgae have shown LC_{50}

values which range between 1.5 mg/L (diatoms) to 50mg/L (green algae) while on marine invertebrates toxicity concentrations have been shown to range from 5.2 mg/L (sea urchins) to 300 mg/L (softshell clam). It should be noted that these concentrations refer to short-term exposure and the concentrations are likely to be much lower for chronic or long-term exposures.

There is little literature available which describes the actual toxic effects of manganese on various organisms. However, in algae manganese is know to induce iron deficiencies which in turn leads to an inhibition of chlorophyll synthesis (Csatorday et al., 1984), as well as increasing the toxicity of other metals.

No LC_{50} values are available for marine fish species, however, LC_{50} values for freshwater fish range from 2.4 mg/L to 3 350 mg/L. Fish, unlike many benthic invertebrates, are highly mobile and are likely to move away from areas where they are experiencing adverse physiological stress. Exposure of freshwater fish to lower levels of manganese over a 96 hr period did not result in any mortalities. However, significant decreases in red blood cells, hemoglobin, mean cell volume, haematocrit and white blood cells were observed (Wepener, 1992). The decrease in red blood cells and haemocrit was due to internal hemorrhaging possibly as a result of necrosis of the intestinal mucosa and kidneys. Anemia was also evident. The decreased mean cell volume was as a result of the release of immature red blood cells as a result of bleeding. These results indicate the severe implications for long-term exposure of fish to manganese. In addition manganese has also been shown to be toxic to the embryonic stages of fish eggs leading to increased mortality (Lewis, 1976), as well as shell disease in crabs and deposition on the gills of lobsters (WHO, 2004).

Using a probabilistic approach, guideline values for manganese toxicity levels have been developed. An overall guidance value for the protection of 95% of the marine species with 50% confidence was derived at 0.3mg/L of manganese (WHO, 2004). This level is considerably lower than effluent discharge concentration and is cause for concern. In order to achieve this concentration a 330-fold dilution would be required which can only be attained with considerable distance; well over 10km from the diffuser. However, it is likely that the manganese will not remain in the water column for a long period and will precipitate out. Manganese has been shown to be present in appreciable amounts in estuarine and marine sediments in areas where there are very low concentrations in the water column (Sadiq 1992). Relatively low concentration of manganese in the water column with higher quantities on the ocean floor indicates that excess manganese precipitates out to the sediments (Sadiq 1992). In terms of the proposed outfall, it is therefore very difficult to assess the implications of the effluent discharge on the local fisheries. In order to get a clearer understanding of the toxic effects of the effluent, chronic exposure tests should be undertaken on local marine species from a range of trophic levels. In short, the manganese concentrations from the outfall would only persist for a period of 6.9 hours (PRDW model). The literature indicates that these concentrations would be problematic if periods of high concentration existed longer than 48 hours, which is not the case for the project. Due to the design and length of the pipeline, manganese would not pose a risk, as rapid dilution is possible.

Sulphate

Limited knowledge exists on the exact fate of sulphate ($S(SO_4)$) in marine ecosystems. There are no known effects or guideline limits set for any natural systems, with the exception of the USEPA, which has set a target value of 250 mg/L for human use. It is not certain if the Malagasy limit is based on this or on verifiable ecotoxicological tests. Tests done on freshwater organisms has shown extremely high tolerance limits for a number of primary producers, and consumers alike (Allen, 2005).

However, it is uncertain how the sulphate will react in the marine environment and if any complex compounds will form. It is recommended that further investigation be done on sulphate and its effect on marine organisms.

Monitoring

The proposed outfall could have impacts of high environmental consequence on most forms of marine life within the region if the conservative estimates of the modelling are exceeded. As seen above, various elements do not need to occur at extremely high concentrations to become toxic. It is therefore planned that a marine water quality and biological monitoring programme be initiated.

Two major aspects of the outfall operation will need to be monitored: suspended solids (turbidity) and induced water quality changes.

Suspended Solid Monitoring

A variety of sampling techniques may be employed to monitor turbidity plumes originating from disposal practices; these may include in-situ sampling, acoustic monitoring, remote sensing and dye tracer studies (Puckette 1998). Each of these techniques was assessed by Probyn (2000), and it is recommended that in-situ collection of water samples for the determination of TSS levels would be the most appropriate. All monitoring and reference sties shall be sampled on a prescribed frequency during operations.

Water Quality Monitoring

In order to quantify the changes in regional water quality, the sample strategy currently underway to assess the baseline conditions of the study must continue into the operational phase. Currently, the focus is on sampling the waters in and around the reefs (reference sites), but once operations begin, water samples will also be taken within the outfall area.

Table 3.9-2 presents a summary of the of proposed target water guidelines, based on known impacts of the various constituents on marine life. Although the Malagasy water quality guidelines were used as the basis of the table, where international limits were more stringent, these were selected. The rationale being that these guidelines were selected based on a sensitive organism known to occur in the Toamasina region. The trophic levels indicated in Table 3.9-2 will be useful in selecting suitable indicator organisms, which are sensitive enough to a particular constituent and could be used in a biological monitoring programme. Species which are frequently monitored in these programmes include algae, mussels and territorial reef fish. Selected sites on Nosy Faho and Le Grand Recif would be ideal long-term monitoring sites.

3.9.4 Marine Outfall Impact Assessment

3.9.4.1 Key Issue - Construction of the Effluent Disposal Pipeline

Issue 1: Specific Impacts on the Nearshore Environment

Impact 1 - : Increased Turbidity As A Result Of Construction

Construction will require the burying of the effluent disposal pipeline above the high water mark as well as sinking the pipeline into the sediments below the low water mark for a short distance. This will require earthworks using heavy machinery along the sandy beach habitats, as well as the re-suspension of underwater sediments using a water jet in order to sink the pipeline to the required depth. This will lead to increased turbidity during the construction phase. Increased turbidity may influence marine organisms by restricting light penetration and by smothering of smaller sessile organisms when sediment resettles. This will lead to a decrease in the availability of food organisms for larger species targeted by local fishermen. The increase in turbidity may also result in the movement of fish away from the construction area.

Table 3.9-2 Suggested target values for the natural marine environment, which should be used as a monitoring guideline.

Parameter	Recommended target values within acceptable variations	Unit	Primary Producers	Primary Consumers	Secondary Consumers
pH	7.3 – 8.5			X	
Conductivity	200	uS/cm			
Hardness	-				
Temperature	+ or – 10C	0C			
TSS	Not increase by 10% above ambient conditions	mg/L	X		
Salinty	33 -36	ppt	X	X	
Al	5	mg/L		X	X
Sb	-	mg/L			
As	0.5	mg/L	X	X	
Ba	100 – 550 ug/L – Mussel embryos	mg/L		X	
Be	-	mg/L			
Bi	-	mg/L			
B	-	mg/L			
Cd	0.02	mg/L		X	X
Ca	-	mg/L			
Cl	-	mg/L			
Co	?: 5 – 10 % variation of background	mg/L			
Cu	0.5	mg/L	X	X	
CrT	0.08 – 0.5	mg/L		X	X
F	20	mg/L			
Fe	3.5	mg/L			
Pb	0.1	mg/L	X	X	X
Li	-	mg/L			
Mg		mg/L			
Mn	5	mg/L			
Hg	0.005	mg/L	X	X	X
Mo	-	mg/L			
Ni	0.25	mg/L		X	X
P	2	mg/L			
K	-	mg/L			
Sc	-	mg/L			
Se	0.02	mg/L		X	X
Na	-	mg/L			
Si	-	mg/L			
SO4	250	mg/L			
Te	-	mg/L			
Th	-	mg/L			
V	0.001	mg/L			
Zn	0.5	mg/L			

[a] The table also indicates the trophic level most affected by changes in a particular constituent and thus would most suitable as monitoring indicators.

Mitigation

The footprint for the pipeline must be minimised as far as possible. The marine outfall will be assembled on land, then floated out to sea, flooded and sunk onto the sea bottom. In developing the detailed engineering design of the outfall, the designer will need to decide whether the pipeline is to be trenched and buried over its full length, or whether the seaward portion can be exposed on the seabed. In the former case, burial depth, together with any armouring provided over the pipe, should be designed for stability against scour and liquefaction under the design loading. In the latter case, the pipeline will require sufficient weight to remain stable under the maximum wave and current loading. No further mitigation or management measures are possible to reduce the impacts during construction.

Residual Impact

The construction activities will result in increased turbidity around the pipeline which will have a severe effect on the local marine resources in the short-term on a local scale. This will possibly result in a slight impact on the local traditional gillnet fishery in the short-term. The overall environmental consequence of the impact will be low.

Impact 2 - Increased Acoustic Noise Levels During Construction - Biota

If the pipeline is submerged for its entire length, the acoustic noise from the use of earthwork equipment on the beaches, and vessels and dredges for burying and sinking the pipeline to the required depth will result in significant noise within close proximity to the construction area.

Mitigation

No mitigation or management measures are possible to reduce the noise impacts.

Residual Impact

The construction activities will result in increased noise levels on a local scale. This will cause moderately severe impacts on the distribution of fish communities on a local level in the short-term. The noise impacts will result in a slight impact on the local gillnet fishery in the short-term on a local scale. The overall environmental consequence is low.

Impact 3: Loss of Benthic Invertebrates

The loss of benthic invertebrates will occur as a direct result of the digging and dredging of the pipeline footprint. Secondary loss of invertebrates outside of the immediate footprint will also occur as a result of the re-suspension of benthic sediments leading to an increase in the suspended solid levels, which will eventually settle out in the surrounding area smothering the benthic fauna in this area. Once construction is complete, the benthic communities are likely to recolonise these areas. The loss of benthic fauna in this region may cause a decrease in the abundance of fish in the area available to the local fisheries.

Mitigation

No mitigation measures are possible.

Residual Impact

The direct loss of benthic invertebrates will occur and will be of slight severity in the local area in the short-term. The secondary loss of benthic fauna may occur in the local area and will be of moderate severity in the medium-term. The overall environmental consequence of this impact is low.

Impact 4 - Impact on Fish

Bony fish, sharks, skates and rays will be in the immediate vicinity of the pipeline footprint. While some may be attracted as a result of the increased turbidity and potential refuge and foraging possibilities it provides, many are likely to disperse from the local area due to the noise and turbidity.

Mitigation

No mitigation measures are possible and it is likely that the fish communities will return once the construction is completed.

Residual Impact

The construction impact on the local fish communities is likely to be slight in the short-term within the local area. This may result in a moderately severe impact on the local fisheries in the short-term in the localised area of the pipeline. The overall environmental consequence of this impact is low.

Issue 2: The Effect of Pipeline Construction on Fishing Activities

Impact 1 - Increased Acoustic Noise Levels During Construction - Fisheries

The use of earthwork equipment on the beaches and vessels and dredges for burying and sinking the pipeline to the required depth will result in significant noise within close proximity to the construction area. Mobile fauna such as fish will move away from the area and therefore reduce the availability of marine resources to the local fishermen.

Mitigation

No mitigation or management measures are possible to reduce the noise impacts.

Residual Impact

The noise impacts will result in a slight impact on the local gillnet fishery in the short-term on a local scale. The overall environmental consequence is low.

Impact 2 - Reduced Access to Traditional Fishing Areas

Construction activities both on the land and at sea will disrupt access of the local fishermen to their traditional fishing areas. The area immediately adjacent to the pipeline will be inaccessible throughout the construction phase, and periodic loss of access to fishing to the south may result during the construction phase due to the use of construction vessels and barges.

Mitigation

There is no mitigation possible during the construction phase.

Residual Impact

During construction, there will be slight short-term impacts to the traditional gillnet fishery. The overall environmental consequence is low.

Impact 3 - increased risk of fishing boat collisions with construction vessels during low visibility/light conditions

The traditional gillnet fishermen who utilize the area around the proposed outfall location most frequently launch their vessels during the early hours of the morning before the sun has risen. Under low visibility conditions, collisions may occur with construction vessels or equipment moored offshore during the construction of the pipeline.

Mitigation

In order to prevent any accidents all moored vessels and infrastructure on the surface will be marked with navigation lights.

Residual Impact

Collisions with construction vessels/equipment may occur on a local level in the short-term and would be of moderate severity. The overall environmental consequence is low.

Impact 4 - Increased Risk of Hydrocarbon Spillage on the Gillnet Fishery

The spillage or leakage of fuel from vessels and storage tanks may occur during the construction phase during which time many large vessels, vehicles and equipment will be in use on a daily basis. There is therefore a risk of contamination of the local beach and marine environment by hydrocarbons. Heavy spillage and contamination will lead to the local extinction of benthic invertebrates on the shoreline and movement away from these areas.

Mitigation

All fuel storage tanks will be appropriately bunded to ensure containment of any spillages and fuelling will only occur in appropriately demarcated and bunded areas in which spill containment equipment is readily available should an accident occur.

Residual Impact

Spillage to the marine or terrestrial environment may occur during the construction phase in the short-term and will be limited to the local construction area. Provided the appropriate mitigation measures are in place, small spills will probably be of slight severity. The impact of any small spill will possibly result in slight impacts to the local gillnet fishery in the short-term. The overall significance of this impact is low.

Should an accident occur resulting in a large spill of hydrocarbons into the marine and shoreline environments the impacts will possibly result in a moderately severe to severe impact on the local area in the short-term. The overall significance of a large spill would be low.

Impact 5: Loss Of Benthic Invertebrates

The loss of benthic invertebrates will occur as a direct result of the digging and dredging of the pipeline footprint. Secondary loss of invertebrates outside of the immediate footprint will also occur as a result of the re-suspension of benthic sediments leading to an increase in the suspended solid levels, which will eventually settle out in the surrounding area smothering the benthic fauna in this area. Once construction is complete, the benthic communities are likely to recolonize these areas. The loss of benthic fauna in this region may cause a decrease in the abundance of fish available to the local fisheries.

Mitigation

No mitigation measures are possible.

Residual Impact

The loss of benthic fauna, a food resource for benthic feeding fish, may cause adecline in the local fishery that will be severe in the medium-term on a local level. The overall significance of this impact is moderate.

3.9.4.2 Key Issue - Operational Phase

Issue 3 – Specific Impacts on the Near Shore Environment

Impact 1 - Effect of Effluent Constituents on Marine Biota

The effluent to be discharged into the marine environment contains a wide variety of minerals, many of which are constituents of seawater. However, the continuous discharge of large volumes of effluent water will lead to the elevation of certain minerals to levels well above those which occur naturally in the Toamasina region. Of particular concern are the high concentrations TSS, manganese and sulphate. The increase in TSS could result in some positive and negative impacts depending on the cumulative effects with the existing baseline levels. Moderate increases in TSS can be advantageous to benthic biota and planktivorous fish provided it has a high organic content and is nutritious as a food source. However, the constituents of the effluent discharge indicate very low organic contents. It is therefore not likely to benefit the benthic filter feeders or planktivorous fish in the area. Increased TSS may be advantageous to small fish species as it provides cover and refuge from predators. Disadvantages of high TSS levels includes reduced light penetration for primary producers, smothering of benthic suspension feeders resulting in reduced food availability for fish. This could change the spatial distribution of fish communities within the immediate area around the effluent discharge pipeline and therefore affect the local fisheries to a large extent. Manganese is generally considered to be non-toxic at low concentrations but has been shown to reduce plant growth and affect the physiology of fish. In addition, the presence of manganese can increase the bio-availability of other trace metals to marine organisms thereby increasing their toxicity. The impacts of the effluent discharge can therefore affect the natural populations of marine biota due to increases in certain constituents' thereby reducing biodiversity of the local area.

Specific consideration will be given to the abundant corals found at Nosy Faho, south of the proposed outfall. The modelling indicates that the plume could move in the direction of Nosy Faho, but due to the dilution factors, the TSS would be similar to present conditions, and the cumulative effect would be low around this reef.

Mitigation

Aside from dilution of the effluent before discharging into the ocean, no mitigation measures are possible. However, additional baseline water quality information will be obtained in the area along with further assessment of environmental health and more detailed information on the fish and fisheries will be obtained (particularly the southern gillnet fishery) prior to construction. Along with effluent water quality monitoring, periodic monitoring of the marine biota to track species distribution, composition and abundance will be implemented to track any changes that may be occurring.

Residual Impact

The discharge of effluent may result in a severe change in species composition and abundance in the local area around the effluent disposal site. This will prevail throughout the operational phase of the mine until natural recovery of the benthic biota occurs once the mine is decommissioned in the long-term. The overall environmental consequence of this impact zone could be high as the zone of influence is a 500 to 1000 m radius around the diffuser. However, the impact occurs within an area of low conservation importance, which already experiences high levels of turbidity. Therefore the overall environmental consequence is predicted to be low.

Issue 4 - Impact on Fisheries Resource

Impact 1 – Reduction Fishery Area Size – Gillnet Fishery

Within the subtidal region the pipeline will be laid on the seabed and held in place by concrete weights. This together with the diffuser will be elevated, with the possibility of entangling the nets of the gillnet fishermen.

Mitigation

In order to reduce entanglement of nets surface marker buoys will be required to mark the exact location of the site. The buoys will have clear navigational lights to facilitate sighting after daylight hours and active engagement with local fishing communities will be undertaken to ensure that they do not utilize the buoy as a fad (fish attracting device) and do not fish within the immediate vicinity of the surface marker buoy.

Residual Impact

The overall impact of the pipeline and diffuser on access to traditional fishing sites will be moderately severe in the long-term in a localized area. The overall environmental consequence is regarded as being low.

Impact 2 - Effect of Outfall Effluent on Fisheries

Moderate increases in TSS can be advantageous to benthic biota and planktivorous fish provided it has a high organic content and is nutritious as a food source. However, the constituents of the effluent discharge indicate very low organic contents, and it is therefore not likely to benefit the benthic filter feeders or planktivorous fish in the area. The only fisheries operating within the area under consideration are the small scale commercial operators and artisinal fishers who occasionally venture out to sea from the ivondro estuary. The line fishery will operates on deeper reefs in the area, none of which are found around the proposed outfall location.

Mitigation

Monitoring of catches within the various fisheries will allow for trends to be identified. Periodic analysis of samples of fish and other marine animal tissue for levels of effluent components will be undertaken as a method of determining the presence of any long-term cumulative effects.

Residual Impact

A change in marine biota may result in a severe to moderate impact in the local fishery in the long-term on a local scale. The overall environmental consequence of this impact is moderate.

Issue 5 – Impact of the Outfall on Tourism

Impact 1 – Reduction in Tourism Potential

The naturally high levels of turbidity mean that any addition due to the outfall is unlikely to be noticed by anyone using the beach facilities. Similarly, the rapid dilution of the effluent components should preclude any adverse effects on beach users or swimmers. Tourism is not a major industry in the immediate outfall area, however, visitors do make use of the beaches on occasion. There may be concern that effluent levels and high turbidity would negatively affect this trade.

Mitigation

Consultation will be conducted with the tourist operators. Disclosure of the pipeline, its purpose and contents, along with monitoring results, will be offered to demonstrate that none of those pose a threat to human life and well being.

Residual Impact

The overall impact of the outfall effluent on the tourism industry will be moderate in the long-term in a local area. The overall environmental consequence is regarded as being low.

3.9.4.3 Summary Of Issues And Impacts

A summary of all the issues discussed above for the construction and operation phases is presented in Tables 3.9-3 and 3.9.4.

Table 3.9-3 Construction Phase Impacts on the Marine Environment

Issue/Impact	Without Mitigation					With Mitigation	
	Risk	Temporal	Spatial	Cert.	Magnitude	Magnitude	Environmental Consequence
Issue 1: Specific Impacts On The Nearshore Environment							
Impact 1:Increased turbidity as a result of construction	will occur	short-term	localized	probable	severe	slight	low
Impact 2: Increased noise levels during construction - biota	will occur	short-term	localized	probable	moderately severe	slight	low
Impact 3: Loss of benthic invertebrates	will occur	medium-term	localized	possible	moderately severe	slight	low
Impact 4: Impact on fish	likely	short-term	localized	possible	moderately severe	slight	low
Issue 2: The Effect Of Pipeline Construction On Fishing Activities							
Impact 1: Increased noise levels during construction - fisheries	will occur	short-term	localized	probable	moderately severe	slight	low
Impact 2: Reduced access to traditional fishing areas	will occur	short-term	localized	probable	slight	slight	low
Impact 3: Increased risk of fishing boat collisions with construction vessels	will occur	short-term	localized	probable	severe	moderately severe	low
Impact 4: Increased risk of hydrocarbon spillage on the gillnet fishery	may occur	short-term	localized	possible	moderately severe	slight	low
Impact 5: Loss of benthic invertebrates	will occur	medium-term	localized	possible	moderately severe	slight	moderate

Table 3.9-4 Operational Phase Impacts on the Marine Environment

Issue/Impact	Without Mitigation					With Mitigation	
	Risk	Temporal	Spatial	Cert.	Magnitude	Magnitude	Environmental Consequence
Issue 3: Specific Impacts On The Near Shore Environment							
Impact 1: Effect of effluent constituents on marine biota including corals	will occur	long-term	localized	possible	very severe	moderately severe	low
Issue 4: Impact On The Fisheries Resource							
Impact 1: Reduction of gillnet fishery area	will occur	long-term	localized	possible	moderately severe	severe	low
Impact 2: Effect of the outfall effluent on fisheries	will occur	long-term	localized	possible	moderately severe	moderate	moderate
Issue 5: The Impact Of The Outfall On Tourism							
Impact 1: Impacts associated with reduction in tourism	will occur	long-term	localized	possible	moderately severe	slight	low

3.9.5 Conclusions

There are limited opportunities to add value from an environmental perspective that will arise from the installation and operation of the marine outfall. Indirect benefits will obviously accrue from the plant and tailings facilities.

The operation of a marine outfall will impact on the marine environment. Due to the naturally occurring turbidity levels, increased turbidity and smothering are unlikely to be significant risks. In addition, levels of contaminants in the effluent and the dilution factors involved mean that the risk of damage to sensitive coral reef habitats is unlikely to be significant, and should not prevent the project from continuing. It is anticipated, however, that public opinion, in particular from the fishing industry may be an issue (Volume A, Section 6).

This assessment, together with baseline data in Volume I, Appendix 10.1, Attachment 2, comprised a snapshot of the nature and condition of the Toamasina reefs to establish the impacts of the proposed marine disposal of effluent from the nickel processing plant is a viable option. A fatal flaw is unlikely, however further quantitative data gathering will be implemented both from a design perspective and to supplement environmental baseline information. The precautionary approach has thus been followed due to the lack of temporal, spatial coverage and accuracy of physical and chemical oceanographic data describing the site specific conditions.

Nevertheless, one can conclude that the Toamasina 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. Consideration must be given to the future improvement in the management of the reef resources in Madagascar as the project proceeds. The effects of the pipeline must thus be minimized 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 Toamasina. They therefore fish predominantly outside of the study area and away from the proposed outfall area in which the effluent will be discharged into the marine environment. It is therefore very unlikely that these fisheries will be impacted by the discharge in any way. The boats utilizing the harbour, however, may suffer from interruptions to their usual routines during the construction phase of the pipeline.

The key fishing areas surrounding the Toamasina port and the proposed location for the effluent discharge pipeline are utilized by the local traditional fishermen on a regular basis. The traditional fisheries are situated closest to the proposed discharge location and it is therefore important to monitor these areas and fisheries as the majority of the fishermen using them are socially and economically dependent on these fisheries for their livelihoods.

The operational impacts could be seen as longer-term effects 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 to 1000 m around the diffuser (based on worst case scenario of maximum flow rate of 4000 m^3/hour with no wind or current). The majority of the effluent within this area 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 Malagasy Guidelines, would always be achieved and the degree of impact would be reduced to negligible as the plume would have been diluted to between 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 information for TSS within the region, this would seem lower than the natural conditions and have a limited cumulative impact. Manganese in turn would be 80% below the Malagasy limits for the worst case scenario. Concentrations above this would not persist longer than 6.9 hours. This time period is important as most marine organisms would respond negatively to exposure for more than 48 hours, which is 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 high conservation value, thus the impact of the nearfield deposition of the outfall would have a low environmental consequence. Preliminary surveys showed only limited community assemblages of fish and a very low species abundances of benthic (bottom living) organisms within this region.

Impacts which would have a moderate ranking 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 upon implementing the mitigations.

3.10 WATER QUALITY

3.10.1 Introduction

This section presents the Environmental Assessment (EA) for the effects of the tailings facility on water and sediment quality, as per the Ambatovy Project (the project) Terms of Reference described in Volume H, Appendix 1.

The project will include the construction, operation and reclamation of a facility to hold the tailings material after it has been treated at the process plant. Groundwater originating from the tailings facility area will be affected by the tailings material and has the potential to change surface water quality downstream of the tailings facility. In addition, development of the tailings facility will involve the collection and diversion of surface runoff in the upper basins of the affected watersheds. As a result, flows in the downstream rivers of the tailings facility will decrease, reducing the dilution (assimilation) capacity of these receiving watercourses.

Groundwater seepages from the tailings facility can also cause changes in sediment quality. Increases in the concentration of substances in the water column may enhance adsorption into the sediment and result in changes in sediment quality. Furthermore, if unmitigated, increased erosion could contribute to changes in substance concentrations in bottom sediments of receiving watercourses.

Water and sediment quality information has been compiled to characterize baseline conditions in the tailings area (Volume I, Appendix 9.1). The available baseline information is used in the following sections to predict and evaluate potential effects of the project on water and sediment quality.

3.10.2 Study Area

The Local Study Area (LSA) for water quality is the same as the hydrology study area for both the tailings facility and process plant, as presented in Volume A, Section 7, Figure 7.2-3. The area includes the likely spatial extent of tailings facility development and effects on water and sediment quality. The LSA for the tailings area includes the subcatchments downgradient of the tailings facility, which drain three tributaries and a reach of the Ambolona River. These features are shown on Volume A, Section, 7, Figure 7.2-3.

3.10.3 Baseline Summary

3.10.3.1 Water Quality

Water quality in the tailings facility area ranges from mildly acidic to neutral with pH values of 5.4 to 7.1. Dissolved oxygen concentrations are generally below saturation. Water temperatures range from 23 to 32°C. Surface waters near the tailings facility area are generally very soft with hardness values of 6 to 26 mg/L as $CaCO_3$. The majority of results for alkalinity indicated that the water bodies within the tailings facility area are potentially sensitive to acidification. Nutrient levels are generally low for nitrogen parameters, including nitrate, nitrite, Total Kjeldahl Nitrogen (TKN) and ammonia, and generally below detection limits for total phosphate.

Based on the Madagascar classification system (Table 3.10-1), background surface water quality in the tailings facility area are typically classified as moderate (Class B), with some watercourses classified as poor quality (Class C). There were no surface waters that are considered to be excessively contaminated (Class HC). Manganese is the only water quality substance with observed concentrations above the World Health Organization (WHO) (2004) drinking water guideline value in the baseline data.

Table 3.10-1 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 ≥ 5	3 < DO < 5	2 < DO ≤ 3	DO < 2
5-day biological oxygen demand (BOD_5)	BOD_5 ≤ 5	5 < BOD_5 ≤ 20	20 < BOD_5 ≤ 70	BOD_5 > 70
chemical oxygen demand (COD)	COD ≤ 20	20 < COD ≤ 50	50 < COD ≤ 100	COD > 100
presence of pathogenic bacteria	no	no	no	yes
Physical and Chemical Factors				
colour (TCU)	colour < 20	20 ≤ colour ≤ 30	colour < 30	n/a
water temperature (°C)	temperature < 25	25 ≤ temperature < 30	30 ≤ temperature < 35	temperature > 35
pH	6.0 ≤ pH ≤ 8.5	5.5 < pH < 6.0 or 8.5 < pH 9.5	pH ≤ 5.5 or pH ≥ 9.5	N/A
total suspended solids (TSS) (mg/L)	TSS < 30	30 ≤ TSS < 60	60 ≤ TSS < 100	TSS > 100
conductivity (µS/cm)	conductivity ≤ 250	250 < conductivity ≤ 500	500 < conductivity ≤ 3000	conductivity > 3000

TCU = True colour unit.
N/A = Not applicable.

Madagascar does not have water quality guidelines for the protection of aquatic life. In the absence of national guidelines, international guidelines from other jurisdictions including Canada (Canadian Council of Ministers of the Environment [CCME] 2003) and the United States (US) (US Environmental Protection Agency [EPA] 2004) were used to screen baseline water quality in the tailings area. Where CCME and EPA guidelines for aquatic life differed, the most stringent guideline from both jurisdictions was used to screen baseline water quality constituents that may be of potential concern. South African Aquatic Ecosystems Guideline (Department of Forest and Water Affairs 1996) were used to compare assessment results because they are the closest regionally approved set of water quality guidelines.

Dissolved oxygen concentrations and pH values were occasionally outside the range for the Canadian and US aquatic life guideline values. CCME or EPA aquatic life guideline values were exceeded by, at least, one measured concentration of aluminum, copper, iron and zinc. However, since the CCME or EPA guidelines do not take into account local ecological conditions in Madagascar, values that do not meet these guidelines should be treated with caution. Indeed, it is not uncommon for baseline water quality data to fall outside the range specified for guideline values even in jurisdictions for which the guidelines have been derived, due to site-specific species and differences in climatic, geological and hydrogeochemical characteristics.

With few exceptions, there are no clear seasonal and spatial patterns in water quality constituents in the tailings facility area. Concentrations of boron and tin appear to be higher in the wet season compared to the corresponding measured data in the dry season. Conversely, levels of total alkalinity, total hardness, bicarbonate, magnesium and zinc are typically higher in the dry season. Detailed water quality conditions in the tailings facility area are presented in Volume I, Appendix 9.1.

3.10.3.2 Sediment Quality

Observed ranges of nitrogen, carbon and phosphorus concentrations in sediment samples collected in the tailings facility area are relatively large, which may be due to the wide range in observed particles size distribution (predominantly coarse material to predominantly fine material).

Madagascar does not have sediment quality guidelines. In the absence of national sediment quality guidelines, results of sediment quality sampling at the site were compared to international guidelines from Canada (CCME 2003) and the US (US National Oceanographic and Atmospheric Association 1999).

Concentrations of substances (except copper and nickel) in bottom sediments are below the corresponding Canadian and US guideline values. However, higher concentrations of copper and nickel in bottom sediments relative to the corresponding guideline values should be treated with caution since derivation of these guidelines did not consider local ecological conditions in Madagascar. Additional details on baseline conditions for sediment quality are provided in Volume I, Appendix 9.1.

3.10.4 Issue Scoping

Surface water concerns of stakeholders and regulators are focused on potential changes to water uses. Downstream water users and aquatic life may be adversely affected by changes in water and sediment quality associated with the construction, operations and closure activities of the tailings facility. In the water basins surrounding the project, the major water uses include domestic, agricultural irrigation (mainly rice paddies) and ecological sustenance.

The following aspects of the project in the tailings facility area could potentially affect water and sediment quality of nearby surface watercourses:

- disturbance of watercourses during the construction of the facility;
- diversion and disruption of natural drainages;
- accidental releases or spills;
- seepage from the tailings facility into downstream watercourses;
- overtopping of tailings impoundment during extreme storm events; and
- runoff from the reclaimed tailings area.

The linkages between project activities and effects on water and sediment quality are shown in Figure 9-14, Volume H, Appendix 9.

The key question for water and sediment quality is:

Key Question SWQ-1 What Effect Will the Tailings Facility Have on Water and Sediment Quality?

3.10.5 Impact Assessment

The proposed tailings facility is located in the upper watersheds of three parallel tributaries to the Ambolona River. The facility will be developed gradually and reclamation will occur progressively. A water management pond will be constructed and used to collect runoff from the tailings impoundment areas. During operations and post-closure, seepages from the tailings facility will discharge to the three headwater tributaries. Also, natural runoff in the upper watersheds will be diverted to a pipeline discharging to the ocean, resulting in reduced flows at downstream locations of the Ambolona River and its headwater tributaries. Reduced groundwater contribution to flow in downstream reaches may also occur due to lower infiltration rates in the tailings facility area. During post-closure, runoff from the tailings facility area will return to baseline levels observed for the natural receiving watercourses. The watersheds of the Ambolona River and the three headwater tributaries are shown in the Hydrology Section (Volume E, Section 3.8).

The construction of the tailings impoundments and water management pond at the tailings facility will involve diversion of watercourses and the removal of vegetation. These two activities have the potential to increase erosion and change sediment transport patterns, which may increase suspended sediment in downstream watercourses and water bodies. Changes in suspended sediment concentrations are addressed in the Hydrology Section (Volume E, Section 3.8).

If accidental releases or spills occur, they could affect water and sediment quality and impair downstream water uses depending on the type of material, magnitude, duration, weather conditions and location of the release or spill. Although no accidental releases or spills were assessed in the water quality section, mitigation activities have been identified to reduce or minimize potential effects. Environmental management systems will be developed and implemented to minimize potential occurrences, characterize water and sediment quality changes and reduce likely effects, if such an event should occur.

During operations and closure, water that seeps through the tailings material will carry substances from tailings porewater and tailings material surfaces into the adjacent groundwater system. Testing of tailings slurry water indicated that tailings seepage is likely to have high concentrations of total dissolved solids, calcium, magnesium, sulphate, cobalt, manganese and nickel compared to background groundwater concentrations. The groundwater that discharges into watercourses and water bodies downstream of the tailings facility will be a combination of tailings seepage and unaffected background groundwater. The effect of the seepage on potential changes in the quality of surface water and bottom sediments is incorporated in models used to predict water and sediment quality due to project activities.

Tailings supernatant and storm water runoff from the tailings facility during operations will be collected in a holding pond and subsequently discharged via pipeline to the ocean. The interception of storm water in the tailings area will reduce streamflows downstream of the facility, with a resulting decrease in the natural dilution capacity of the receiving surface waters. Reduction in dilution capacity has the potential to change water quality in watercourses and water bodies downstream of the tailings facility. This aspect was assessed using a mass balance model.

The tailings facility will be designed to contain the 1-in-50 year storm event. During larger storm events, water in excess of 1-in-50 year storm will be released to the downstream watercourses and water bodies. Increased erosion from high runoff may increase sediment loading to downstream watercourses and water bodies. Changes in total suspended solids (TSS) concentration due to potentially higher sediment loading are addressed in the Hydrology Section (Volume E, Section 3.8).

With the exception of TSS, water quality constituents will be substantially diluted due to the large volumes of water during large storm events. This dilution should cause concentrations of most water quality constituents to be lower than the corresponding values during average flow conditions used in the water quality model. Based on the predicted changes in water quality, changes in sediment quality are expected to be negligible. Therefore, this potential impact was not assessed further for water or sediment quality.

During post-closure, runoff from the tailings impoundment will be redirected to the natural receiving watercourses. The quantity and quality of runoff will be different from flows and water quality under baseline conditions. This change in runoff has the potential to affect water quality in downstream receiving watercourses and water bodies. This potential impact was assessed using a mass balance model.

Changes in water quality, particularly for metals and nutrients that tend to be adsorbed to sediment particles, may cause changes in sediment quality in receiving watercourse and water bodies. Also, without effective mitigation, sediment transported and deposited in downstream watercourses and water bodies may affect substance concentrations in bottom sediments. This impact pathway was assessed further using a sediment quality model.

3.10.5.1 Assessment Methods

The assessment process of water and sediment quality involved:

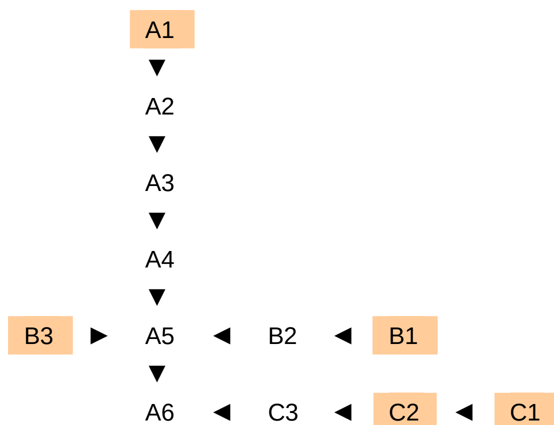
- identification of appropriate mitigation activities;

- modelling of water and sediment quality changes based on the selected mitigation activities;
- comparison of predicted water and sediment quality to baseline concentrations and guideline values; and
- assessment of project effects on human, flora, fauna and aquatic health.

The assessment of the effects of changes in water and sediment quality on biological receptors is described in Volume E (Sections 4.1 to 4.3 and 5.4).

Water quality concentrations were predicted at the downstream end of twelve assessment nodes (Figure 3.10-1) for six scenario snapshots. These assessment nodes and scenarios were also used for hydrological assessment completed in Volume E, Section 3.8.

Figure 3.10-1 Schematic of Basins Affected by Tailings Facility



Note: shaded cells will receive seepage directly from the tailings facility.

The individual basins for each assessment node were grouped as follows:

- Ambolona Tributary 1 (basins A1 to A4);
- Ambolona Tributary 2 (basins B1 to B3);
- Ambolona Tributary 3 (basins C1 to C3); and
- Ambolona River (basins A5 and A6).

The six water quality assessment scenarios correspond to key phases that represent baseline, operations, post-closure and far-future conditions in the tailings facility area. The scenarios are listed below:

- baseline;
- year 14 (End of Phase I);
- year 20 (End of Phase II);
- year 27 (End of Phase III);
- 15 years after closure; and
- 80 years after closure.

Each of the scenarios will have a distinct combination of groundwater and surface water runoff characteristics for quantity and quality of flow in receiving watercourses and water bodies. The resulting sediment quality will also be unique for each scenario. Detailed descriptions of how different phases of the project are expected to affect groundwater and surface flows are described in Hydrogeology (Volume E, Section 3.7) and Hydrology (Volume E, Section 3.8), respectively.

Water Quality

A mass balance model was used to conservatively assess changes in water quality due to seepage from the tailings facility and reductions in flows downstream of the tailings facility. The mass balance model was based on the following assumptions:

- no attenuation or dilution of substance concentration occur as seepage travels through the groundwater system to surface waters;
- fully mixed conditions in surface waters;
- no geochemical transformations occur in groundwater or surface waters;
- no runoff from the tailings facility will be routed to receiving watercourses during operations;
- a well network is installed downstream of the tailings facility area to remove the seepage downstream of the tailings facility from the start of operations to fifteen years after closure;
- substance concentrations in tailings seepage will be the same as the corresponding predicted values in the slurry water tests (Penttinen 2005) with no dilution occurring; and
- sustainable reclamation and appropriate mitigation will effectively isolate tailings material from runoff flows during post-closure.

The following mass balance equation was used to calculate substance concentrations at each assessment node for both dry and average flow conditions representing each of the six scenarios. Flows from the driest month, November, were used represent dry flow conditions and annual averages were used to represented average flow conditions.

$$C_{mix} = (C_{cleangw}Q_{cleangw} + C_{seep}Q_{seep} + C_{sur}Q_{sur})/ (Q_{cleangw} + Q_{seep} + Q_{sur}) \quad \text{Equation 1}$$

Where:
- C_{mix} = substance concentration at assessment node
- $C_{cleangw}$ = substance concentration in natural groundwater
- $Q_{cleangw}$ = natural groundwater flow to the node
- C_{seep} = substance concentration in tailings seepage
- Q_{seep} = seepage rate to assessment node
- C_{sur} = background substance concentration in surface runoff reporting to the assessment node
- Q_{sur} = background surface runoff reporting to the assessment node.

Surface and total groundwater flows (including seepage and natural groundwater) for dry and average conditions were obtained from the hydrology (Volume E, Section 3.8) and hydrogeology sections (Volume E, Section 3.7). Combined substance loadings from seepage and natural groundwater were obtained from Groundwater Consulting Services (GCS 2005). The combined substance loadings from groundwater, and seepage and substance concentrations in tailings seepages are provided in Tables 9.2-1 and 9.2-2 of Volume I, Appendix 9.2. These loadings and concentrations were used to estimate the proportion of tailings seepage in the total groundwater flow to an assessment node, based on the following equation:

$$Load_{gw} = (Q_{gw} – Q_{seep})*C_{cleangw} + Q_{seep}*C_{seep} \quad \text{Equation 2}$$

Where:
- $Load_{gw}$ = total substance loading from seepage and natural groundwater
- Q_{gw} = total groundwater flow

Equation 2 was solved to obtain Q_{seep}.

Concentrations of natural groundwater and seepage were based on average baseline concentrations (CGS 2005) and tailings effluent concentrations provided by Dynatec (Penttinen, 2005), respectively. The tailings effluent concentrations were characterized by the processed slurry sample (pail 42) that was considered to be most representative of actual operating conditions (Penttinen, 2005).

The concentration of the surface runoff was back-calculated based on the concentrations and flows observed during baseline conditions in the watercourses within the tailings facility area. The following mass balance equation was used:

$C_{sur} = ([Q_{sur} + Q_{gw}] * C_{mixb} - Q_{gwb} * C_{gwb})/Q_{surb}$ Equation 3

Where: C_{mixb} = average baseline substance concentrations in surface watercourses within tailings facility area

Q_{gwb} = baseline groundwater flow

C_{gwb} = average baseline substance concentration in groundwater

Q_{surb} = baseline surface runoff contribution to total streamflow.

Concentrations of the surface runoff were estimated for both dry and wet seasons. Dry season concentrations were based on baseline water quality and flows observed during dry conditions. Wet season concentrations were calculated using baseline water quality observed during the wet season and average flow conditions. Average water quality conditions were based on average baseline water quality observed during the wet and dry seasons and average flow conditions.

All water quality constituents for which sufficient data were available were predicted at the assessment nodes within the tailings facility area (Table 3.10-2). Values for pH were not predicted with the mass balance model. However, the potential range of instream pH value was characterized for all scenarios using observed and predicted pH values for baseline flows and tailings seepage, respectively.

Table 3.10-2 Water Quality Constituents Assessed in the Tailings Facility Area

Group	Water Quality Variables
conventional	total alkalinity and conductivity
major ions	calcium, chloride, magnesium, sodium and sulphate
nutrients	nitrate and nitrite
total metals	aluminum, arsenic, barium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, silicon, vanadium and zinc

Whole Effluent Toxicity Assessment

Whole effluent toxicity testing is an effective method of accounting for synergistic or additive toxic effects of complex mixtures. The term acute toxicity refers to the potential for a given water, as a whole, to result in acute (i.e., mortality due to short-term exposure) effect on aquatic organism exposed to that water.

Definitive expressions for acute toxicity are developed by exposing test organisms to several different dilutions of the test water for a specified period of time and assessing the response of the test organisms (Volume I, Appendix 9.2, Attachment 2, Table 9.2-18). Acute toxicity is generally expressed as the percentage of test water (as diluted with clean water) required to kill 50 percent of the test population, also known as the LC_{50} concentration. Thus low LC_{50} concentrations represent greater toxicity. These values are determined under controlled conditions in a laboratory using water mixtures that are likely to be present during operation and/or reclamation.

For the purpose of water quality modelling, the LC_{50} value assigned to the tailings effluent was converted to acute toxicity units (TUa) by dividing 100% by the LC_{50} value. This approach for modelling whole effluent toxicity is consistent with USEPA (1991) protocols. The maximum combined surface water value of TUa was calculated for the scenario with the highest ratio of tailings seepage to surface water based on the following equation:

$$TUa_{mix} = (1-F_{seep}) * TUa_{sur\ and\ cleangw} + F_{seep} * TUa_{seep} \qquad \text{Equation 4}$$

Where:

TUa_{mix}	=	maximum acute toxicity at assessment node
F_{seep}	=	maximum fraction of the flow originating from tailings facility to total assessment node
$TUa_{sur\ andcleangw}$	=	acute toxicity of overland runoff and clean groundwater
TUa_{seep}	=	acute toxicity of seepage from the tailings facility

The acute toxicity of the overland flow and clean groundwater were assumed to be zero because the quality of these waters will be equivalent to baseline conditions, which have no observed acute toxicity effects. The acute toxicity units of the seepage was based on the LC_{50} of the most sensitive tested organism.

The predicted maximum acute toxicity in receiving watercourses due to effects of tailings seepage was provided to the human and ecological health discipline (Volume E, Section 5.4) for receptor effects assessment.

Sediment Quality

Changes in sediment quality were predicted based on USEPA (1999) guidelines for calculating benthic sediment concentrations. The equations provided by USEPA (1999) estimates the proportion of a substance within a waterbody that exists in sediments, using chemical partition coefficients, sediment porosity, total suspended solids concentration, water depth and depth of benthic sediments.

Changes in sediment quality during operations and post-closure were calculated based on water quality predictions described in the previous section. The sediment quality calculations assumed that sediment load to receiving downstream watercourses and water bodies will be negligible due to implementation of appropriate mitigation. Where available, baseline sediment concentrations were used to calibrate the sediment quality model. The equations are provided in Volume I, Appendix 9.2. The inputs to the sediment quality model are provided in Volume I, Appendix 9.2.

Changes in sediment concentrations were assessed for all metals that were assessed in the water quality model and had baseline sediment quality data, including: aluminum, arsenic, barium, chromium, cobalt, copper, lead, manganese, mercury, nickel, vanadium, zinc and iron. Although baseline sediment quality data were not available for chromium, changes in chromium sediment concentrations were assessed because of predicted changes in chromium water quality concentrations.

3.10.5.2 Assessment Criteria

Comparison to Baseline Values and Guidelines

Maximum concentrations predicted for the dry and wet seasons and average conditions during operations and post-closure scenarios were compared to corresponding baseline values. Maximum substance concentrations that exceed baseline values by 10% or greater were considered to be appreciably affected by project-related activities, and these concentrations were further compared to the corresponding drinking water and aquatic life guideline values.

Drinking water guidelines were based on the WHO drinking water quality guidelines (WHO 2004) and aquatic life guidelines were based on the South African Aquatic Ecosystems Guideline (Department of Water Affairs and

Forestry 1996). Madagascar does not currently have guidelines for aquatic life. CCME and EPA aquatic life guidelines, which represent a very stringent set of guidelines primarily based on North American literature, were used as a screening tool to flag potential parameters of concern in the baseline water quality. However, South African guidelines represent the closest regionally approved set of guidelines and are considered to be more appropriate to evaluate effects of water quality changes in Madagascar.

Predicted sediment quality results were compared to baseline sediment quality values and Canadian sediment quality guidelines (CCME 2003). Canadian guidelines were used because there were no locally or regionally approved sediment quality guidelines.

Predicted maximum acute toxicity value was compared to the USEPA (1991) in-stream guideline for acute toxicity (0.3 TUa).

Results of the comparison to baseline and guideline values for water and sediment quality are summarized in Volume I, Appendix 9.2. The effects of the predicted changes on biological receptors are assessed separately in Volume E for flora, fauna, fish and aquatic resources and human and ecological health.

Selection of Key Water Quality Substances

Five representative key substances were selected to characterize potential changes in water quality from the tailings area, including cobalt, copper, manganese, nickel and zinc. Predicted results from the operations scenarios of copper, manganese and zinc were greater than 10% above baseline and above South African guidelines. Cobalt and nickel were also included since these are the desired elements to be mined.

The predicted concentrations of these five substances were summarized at the assessment nodes in each basin, for operations and post-closure scenarios under dry and average flow conditions.

3.10.5.3 Mitigation

Mitigations incorporated into the water quality model include:

- diverting runoff from the tailings facility to the ocean to prevent substance loading from entering downstream watercourses and water bodies during operations via runoff;

- installing a liner in the water management pond to minimize seepage from the pond;
- installing a well network to intercept and remove tailings seepage downstream of the tailings facility from the beginning of operations to fifteen years after closure;
- progressively reclaiming the tailings facility areas through revegetation and the use of native (non-tailings) material; and
- establishing a sustainable reclamation drainage plan at closure.

A liner will be used to reduce seepage from the water management pond. No liner will be used in the tailings pond because it was determined, through groundwater modelling, that the consolidated tailings material was suitably effective at reducing seepage (Groundwater Consulting Services [PTY] Ltd. 2005).

A network of interception wells will be drilled to intercept the seepage from the tailings facility. The intercepted seepage will be managed with the water contained in the tailings holding pond.

During operations, runoff from the tailings facility, which will have been in contact with the tailings material, will be collected in a water management pond and discharged via a pipeline to the ocean. Therefore, there are no water quality substance loads from contaminated runoff entering the downstream watercourses. See Volume E, Section 3.9 for an analysis of marine impacts.

At closure, a sustainable reclamation drainage plan will be developed. A layer of soil cap material will fully cover the tailings material to prevent contact with surface water flows during the post-closure phase. The seepage will be intercepted and monitored until monitoring results indicate that the seepage can be released to the environment without adverse aquatic effects.

Other mitigations to minimize water quality changes due to project-related activities include:

- implementation of runoff and sediment control procedures during site clearing and preparation to minimize the introduction of sediments to receiving watercourses and water bodies;
- implementation of a waste management plan for the handling and storage of all hazardous materials; and

- development and implementation of an effective emergency and spill response plan as a component of an overall Environmental Management System.

During construction, operations and closure, erosion control measures will be implemented to minimize the removal and transport of soil material by water and wind into downstream watercourses and water bodies.

3.10.5.4 Results

Water Quality

Model results for all scenarios, basins, nodes and seasons were provided to disciplines assessing human, flora, fauna and aquatic health and are presented in Volume I, Appendix 9.2.

Predicted maximum concentrations were compared to baseline concentrations, and drinking water and aquatic life guideline values (Table 3.10-3). A summary of results, which includes a comparison to baseline and guidelines values, is provided for all modelled parameters in Table 3.10-3.

During operations, the maximum concentrations of eleven out of the twenty-three modelled constituents were higher than baseline concentrations (Table 3.10-3). Out of the eleven constituents above baseline, none were above WHO drinking water guidelines, but three (copper, manganese and zinc) were greater than South African Ecosystems Guidelines. The predicted increase in copper and zinc were marginal, which indicates that manganese is the critical substance within the tailings area. The effects of the predicted results for these three metals are further assessed as described in Section 5.4 (Human and Ecological Health). Predicted levels of conductivity, sulphate, calcium, magnesium, iron, silicon and cobalt in operations were appreciably greater than baseline levels but there are no WHO or South African guidelines for these substances. Predicted concentrations of nitrate were also above baseline levels in operations but not above the WHO drinking water guideline for nitrate.

Table 3.10-3 Maximum Predicted Water Quality Concentration From Tailings Area Versus Baseline and Guideline Values

Parameter	Operations Scenarios			Post-Closure Scenarios		
	Baseline	WHO Drinking Water Guidelines[(a)]	South Africa Aquatic Ecosystems Guideline[(b)]	Baseline	WHO Drinking Water Guidelines[(a)]	South Africa Aquatic Ecosystems Guidelines[(b)]
conductivity	√	NG	NG	√	NG	NG
total alkalinity as $CaCO_3$	-			-		
nitrate (NO_3)	√	-	NG	√	-	NG
nitrite (NO_2)	-			-		
calcium (Ca)	√	NG	NG	√	NG	NG
chloride (Cl)	-			-		
magnesium (Mg)	√	NG	NG	√	NG	NG
sodium (Na)	-			-		
sulphate (SO_4)	√	NG	NG	√	NG	NG
aluminium (Al)	-			-		
arsenic (As)	-			-		
barium (Ba)	-			-		
chromium (Cr)	-			-		
cobalt (Co)	√	NG	NG	√	NG	NG
copper (Cu)	√	-	●	√	-	●
iron (Fe)	√	NG	NG	√	NG	NG
lead (Pb)	-			-		
manganese (Mn)	√	-	●	√	-	●
mercury (Hg)	-			-		
nickel (Ni)	-			-		
silicon (Si)	√	NG	NG	-		
vanadium (V)	-			-		
zinc (Zn)	√	NG	●	-		

(a) World Health Organization Drinking Water Guidelines (WHO 2004).
(b) South Africa Ecosystems Guideline (Department of Water Affairs and Forestry 1996).
- Not above baseline (less than 10% difference between baseline and maximum predicted concentration or guideline value).
√ Project-related changes in water quality concentrations are above baseline values by 10% or greater.
● Above guideline.
Blank cell Not compared to guidelines when projected-related activities results in less than 10% difference in maximum predicted concentration compared to baseline value.
NG No applicable guideline.

For the post-closure scenarios (i.e., 15 and 80 years after closure), eight out of the twenty-three modelled parameters were above baseline concentrations (Table 3.10-4). Out of these eight parameters above baseline, none were above WHO drinking water guidelines and only copper and manganese were greater than South African Aquatic Ecosystems Guidelines. The predicted increase in copper is marginal and the exceedance of the South African Ecosystems Guideline is primarily due to background conditions. The effects of the predicted results for these two metals are further assessed as described in Section 5.4 (Human and Ecological Health). Predicted levels of conductivity, sulphate, magnesium, iron and cobalt in operations were appreciably greater than baseline levels but there are no WHO or South African guidelines for these substances. Predicted concentrations of nitrate were also above baseline levels in operations but not above the WHO drinking water guideline for nitrate.

Predicted concentrations in operations and post-closure scenarios were compared to South African Aquatic Ecosystems Guideline values for those substances with predicted increase in concentrations above baseline values (Table 3.10-4). Only wet and dry season results are presented in Table 3.10-4 because results based on average conditions (i.e., average of wet and dry season water quality and average flows) were within the range of results predicted for wet and dry seasons. The table is organized by season for the three tributaries to the Ambolona (basins A1 to A4, B1 to B3 and C1 to C3) and the reach of the Ambolona within the LSA (Basins A5 to A6). In general, the highest water quality concentrations predicted for the operations and post-closure scenarios occurred during the dry season.

In the operations scenarios, manganese concentrations are predicted to increase in all assessed watercourses and be above the South African Ecosystems Guideline in one watercourse (Ambolona tributary 1). Maximum predicted concentrations of copper were marginally above baseline levels and above South African Ecosystems Guideline in two watercourses (Ambolona Tributaries 1 and 3) during the dry season. Predicted concentrations of copper did not increase in the wet season results. Zinc concentrations which are above the South African Ecosystems Guideline values during baseline conditions are predicted to increase marginally in one basin (the upstream basin of Ambolona tributary 2 [B1]) during one operations phase (Year 27) under both wet and dry conditions. The exceedance of the South African Ecosystems Guideline is primarily due to high background levels.

In the post-closure scenarios, concentrations of manganese continue to be above baseline levels. The predicted concentration of manganese is above the South African Ecosystems Guideline value in one watercourse (Ambolona tributary 1) in the short-term (i.e., 15 years) post-closure scenario but not in the long-term (i.e., 80 years) post-closure scenario. Copper continues to be marginally above baseline levels in the dry season post-closure scenarios in all basins, with the exception of the Ambolona River (basins A5 and A6). These predicted copper concentrations are also above the South African Ecosystems Guideline value, but the largest contribution to the guideline exceedance is due to background copper levels. Zinc concentrations return to baseline levels in the post-closure scenarios.

The higher predicted levels in conductivity, sulphate, calcium, magnesium, cobalt, copper and manganese during both operations and post-closure scenarios are due to loadings from the tailings seepage. These substances are higher in the tailings seepage compared to the baseline surface water quality for the corresponding season. Predicted tailings seepage concentrations for sulphate, magnesium and manganese were much higher than the corresponding baseline surfacewater values. Predicted concentrations of nitrate, iron, silicon and zinc are above baseline values in the operations and post-closure scenarios due to the predicted change in the ratio of groundwater to surface flows. Baseline surface water concentrations for nitrate and iron are greater than baseline groundwater and tailings seepage concentrations. Baseline groundwater concentration of silicon and zinc are already greater than tailings seepage concentrations.

A summary of predicted concentrations for the five key representative substances; copper, cobalt, manganese, nickel and zinc is provided below. Full results are presented for each of the twelve basins in Volume I, Appendix 9.2.

All of the five key parameters, with the exception of manganese, were predicted to occur at levels similar to baseline conditions during operations and post-closure. Copper and zinc for both the baseline levels and predicted levels exceeded the South African guidelines. In the case of manganese, during operations and post-closure, the highest concentrations are predicted to occur in Basin A1. Other basins predicted to have elevated manganese concentrations are B1 (operations and post-closure) and C1 (post-closure only). In general, concentrations decreased downstream of Basins A1, B1 and C1 for the operations and post-closure scenarios. With the exception of manganese concentrations predicted in Basin A1, all predicted concentrations of manganese are below South African Guideline values from operations to post-closure.

Table 3.10-4 Maximum Predicted Concentrations Above Baseline or South African Guidelines (Operations and Post-Closure)

Operations Scenarios								
Parameter	**Basin A (A1 to A4)**		**Basin B**		**Basin C**		**Basin A (A5 to A6)**	
	Wet	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**
conductivity	-	√	-	-	-	√	-	√
nitrate (NO_3)	-	√	-	-	-	√	-	-
calcium (Ca)	-	-	-	√	-	-	-	-
magnesium (Mg)	√	√	√	√	-	-	-	√
sulphate (SO_4)	√	√	√	√	-	-	√	√
cobalt (Co)	-	√	-	-	-	-	-	-
copper (Cu)	-	●	-	-	-	●	-	-
iron (Fe)	-	√	-	-	-	√	-	-
manganese (Mn)	√	●	√	√	-	-	√	√
silicon (Si)	-	-	n/a	√	-	-	-	-
zinc (Zn)	-	-	●	●	-	-	-	-
Post-Closure Scenarios								
Parameter	**Basin A (A1 to A4)**		**Basin B**		**Basin C**		**Basin A (A5 to A6)**	
	Wet	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**
conductivity	-	√	-	√	-	√	-	√
nitrate (NO_3)	-	√	-	√	-	√	-	√
magnesium (Mg)	√	√	√	√	-	-	-	-
sulphate (SO_4)	√	√	√	√	√	√	√	√
cobalt (Co)	-	√	-	√	-	√	-	-
copper (Cu)	-	●	-	●	-	●	-	-
iron (Fe)	-	√	-	√	-	√	-	√
manganese (Mn)	√	●	√	√	√	√	√	√

Not above baseline (less than 10% difference between baseline and maximum predicted concentration or guideline value).

√ Project-related changes in water quality concentrations are above baseline values by 10% or greater.

● Project-related changes in water quality concentrations are above baseline values by 10% or greater and above guideline.

n/a Substance not modelled for this season because baseline data were not available.

Predicted copper concentrations followed a pattern similar to that discussed above for manganese. From operations to post-closure, the highest concentrations are predicted to occur in Basin A1 and elevated concentrations are predicted at B1 (post-closure only) and C1. Concentrations will generally decrease downstream of Basins A1, B1 and C1 for all scenarios. Predicted copper concentrations were above baseline concentrations by greater than 10% and South African Guideline values in the following basins under dry season conditions:

- A1, C1, and C2 (operations and post-closure); and
- B1, B2, and C3 (post-closure only).

Concentration of zinc during the dry season is predicted to be above the baseline value by more than 10% at B1 for the Year 27 scenario. This concentration was also above the South African Aquatic Ecosystems Guideline value for zinc.

Predicted concentrations of cobalt and nickel were not substantially different from baseline concentrations at any of the basins and were all below applicable guideline values.

Whole Effluent Toxicity Assessment

The predicted maximum acute toxicity was calculated to be 0.0031, which is appreciably below the in-stream guideline value of 0.3 (USEPA 1991). This calculation was based on an LC_{50} concentration of 31.1% for the most sensitive species (*Daphnia magna*) and the maximum fraction of tailings seepage to instream flows of 0.095%. The potential impacts of the maximum predicted acute toxicity value are assessed in the sections of the EA related to ecological health (Volume E, Section 5.4).

Sediment Quality

The results of the sediment quality assessment indicated that out of the eighteen metals assessed, predicted changes in sediment concentrations of arsenic, selenium and thallium were greater than baseline due to project-related activities. However, the maximum predicted value of arsenic concentration in sediment was well below the Interim Sediment Quality Guideline (ISQG) (CCME 2003) value, and selenium and thallium do not have Canadian sediment quality guidelines (Table 3.10-5). Chromium concentrations were also predicted to increase by approximately 0.005 and 0.006 mg/kg for operations and post-closure conditions, respectively. Absolute values for chromium sediment concentration could not be compared to CCME guidelines because no baseline data were available.

However, an increase in concentration of 0.006 mg/kg is considered to be small relative to the CCME ISQG of 37.3 mg/kg.

Table 3.10-5 Predicted Maximum Concentration in Bottom Sediment in the Tailings Area Versus Baseline and Guideline Values

Parameter	Operations			Post-closure		
	Results Above Baseline Sediment Concentration	Results Above Canadian Sediment Guidelines		Results Above Baseline Sediment Concentration	Results Above Canadian Sediment Guidelines	
		ISQG[(a)]	PEL[(b)]		ISQG[(a)]	PEL[(b)]
aluminum	-			-		
arsenic	-			-		
barium	-			-		
chromium	√	-	-	√	-	-
cobalt	-			-		
copper	-			-		
lead	√	-	-	√	-	-
manganese	-			-		
mercury	√	-	-	√	-	-
nickel	-			-		
vanadium	-			-		
zinc	√	NG	NG	-		
iron	-			-		

(a) Probable Effect Level (CCME 2003).
(b) Interim Sediment Quality Guideline (CCME 2003).
- Not above baseline (less 10% difference between baseline and maximum predicted concentration) or guideline value.
√ Project-related changes in water quality concentrations are above baseline value by 10% or more.
Blank cell Not compared to guidelines when projected-related activities results in less than 10% difference in maximum predicted concentration compared to baseline value.
NG No applicable guideline.
Note: Because baseline concentrations were not available for chromium, it was assumed that predicted maximum concentrations were above baseline concentrations. If a 0.006 mg/kg increase would have caused concentrations to increase above the ISQG, than this would have resulted in an increase of less than 10% from baseline.

3.10.5.5 Impact Analysis

Prediction Confidence

The main potential sources of uncertainties in the water and sediment quality assessment include surface and groundwater flows, baseline water quality, seepage quality and runoff water quality. The prediction confidence of the surface water flows was medium for average flows and low for dry season flows, as discussed in Volume E, Section 3.8. The baseline status of surface water in the dry season and groundwater quality conditions in the LSA are adequately understood. Measured surface water quality in the wet season is based on high analytical detection limits; therefore, many data sets are below the corresponding detection limits. Thus, substance concentrations used in the water quality model to characterize baseline conditions in the wet season are potentially higher than the actual concentration levels, resulting in more conservative predictions of surface water quality.

A medium level of uncertainty is associated with the substance concentrations in seepage. Although the substance concentrations in seepage were based on one slurry sample, the treatment process can be controlled to effectively meet the predicted water quality for the sample.

Conservative assumptions were made in the modelling process. Model assumptions included the conservative behaviour of all water quality substances (no precipitation, attenuation or geochemical transformations in the groundwater and surface waters) and no dilution of the tailings effluent within the tailings facility. The proposed reclamation measures are also based on standard practices, which are known to be effective in reducing effects from tailings facilities on water and sediment quality during post-closure. There is high to medium confidence in the success of the mitigations.

The overall prediction confidence for this assessment is considered to be medium due to low to high uncertainty of source data for the water and sediment quality models, conservative assumptions incorporated into the models and demonstrated success of the proposed mitigations.

Monitoring

The water and sediment quality monitoring program will be designed to ensure protection of surface water and sediment quality and to identify any unanticipated effects. The key parameter to be monitored will be manganese along with other basic water quality parameters. The purpose of identifying unanticipated effects and their cause is to adaptively manage or mitigate these impacts quickly and effectively.

Water quality monitoring will be conducted for collected water in the tailings holding pond, groundwater from the seepage collection system, and at key locations in the downstream water sources during operations and post-closure. Monitoring will continue, during the short-term and long-term closure scenarios, until results indicate that seepage from the tailings facility will have no significant effect in downstream assessment nodes.

Monitoring of the effectiveness of erosion control measures, slope stability, and reclamation success are described in Volume E, Section 6.

3.10.5.6 Conclusions

Based on the above assessment of water and sediment quality, the following main conclusions have been identified:

- Seepage from the tailings facility is a potential major source of sulphate, magnesium and manganese loadings to receiving watercourses and water bodies during project operations. Main mitigation involves groundwater pump back from below the tailings facility (see Section 3.7 this volume).
- Seepages from the tailings facility also increase conductivity levels in, and contribute loadings of calcium to, receiving waters during operations.
- Of the key substances observed, the project will not cause substance concentrations to increase above WHO drinking water guideline values in receiving waters downstream of the tailings facility areas.
- Manganese is the key substance of concern with project-related loadings during operations and post-closure potentially increasing concentration of this substance in all basins, with the exception of Basin C (tributary 3 of the Ambolona River), above baseline concentrations.
- The highest concentrations of manganese during operations will occur in Basin A1 (the most upstream basins of Tributary 1 of the Ambolona River) and will be over the South African Ecosystems Guideline value. Concentrations of manganese will be below the South African Guideline value in all other basins.
- Water quality concentrations of manganese during post-closure phases for the short-term (15 years) period are above baseline levels and the South African Aquatic Ecosystems Guideline.
- Water quality concentrations of manganese during post-closure phases for the long-term period are above baseline levels but below the South African Ecosystems Guideline.
- Sediment quality in receiving watercourses and water bodies during tailings facility operations and post-closure will remain similar to observed baseline levels due to effective erosion control measures, sediment ponds and sustainable reclamation activities.
- An assessment of water quality effects on human and ecological health is provided in section 5.4 of this volume.

3.11 VISUAL AESTHETICS

3.11.1 Introduction

This section presents the Environmental Assessment for the effects of the tailings facility on visual aesthetics. As per the Ambatovy Project (the project) Terms of Reference, the viewshed for the tailings facility is determined and the potential impacts on the nearest habitations or frequented viewpoints are evaluated.

3.11.2 Study area

The tailings facility Local Study Area (LSA) for visual aesthetics is an area within 5 km of the tailings facility in all directions, as shown in Volume A, Figure 7.2-3. This study area is designed to include the limits of the area in which the tailings facility is close enough to be a prominent visible feature within the local terrain.

3.11.3 Baseline summary

The valleys in which the tailings facility is planned are characterized by moderately steep, partially forested hillsides (valley walls) which descend into flat, wide valley floors. 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.

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 3.11-1. Baseline views from key viewpoints TF1 to TF4 are presented in Volume I, Appendix 11.1, Attachment 1, Photographs 20 through 23.

Additional details concerning baseline conditions are provided in Volume I, Appendix 11.1.

Table 3.11-1 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

Note: GPS = global positing system; UTM = universal transverse mercator.

3.11.4 Issue Scoping

In public consultations, the main issue of concern expressed by the National Association for the Management of Protected Areas (ANGAP) has been the potential effects of visual impacts on tourism. Areas in and around the tailings facility are not considered important tourism areas, but given the proximity of the area to Toamasina, some potential exists for future tourists to view this area. Potential changes that will be seen by local residents, as well as tourists and other visitors include:

- removal of vegetation and changes in landforms, with the development of a widened linear access route, dams and the pond area;
- generation of visible dust along the linear access route in dry periods, as well as some locally visible fossil fuel emissions;
- a limited amount of night time lighting from infrastructure at the site; and
- the presence of buildings, facilities and infrastructure, some of which will be visible from outside of the tailings facility property.

The key question for visual aesthetics is:

Key Question VA-1 What Effect Will the Tailings Facility Have On Visual Aesthetics?

Visual effects will occur during the construction, operation and closure phases of the tailings facility, similar to the linkages for visual aesthetics at the mine site (Volume H, Appendix 9).

3.11.5 Impact Assessment

During construction and operation phases, vegetation will be cleared, landscape features will be altered, industrial buildings will be constructed and at times, dust will be released from the tailings facility. Following closure, most sources of visual impacts will be removed, but altered landforms will remain.

3.11.5.1 Assessment Methods

Topographic information, photographs and on-site observations were used to describe current views. Baseline topographic data and project topography models were used to develop digital elevation maps from which to generate viewsheds. Key viewpoints affording "worst case" views from locations close to the tailings facility were selected and ground-level views were generated using topographic models.

An overall overhead view of the tailings facility topography at its maximum development phase (year 27) was generated to provide a visual impression of the project as a whole for readers; however, this view is not representative of a typical view to be seen by local residents or tourists from ground level, and was not used to evaluate visual impacts.

3.11.5.2 Assessment Criteria

The assessment criteria used for visual aesthetics are presented in Table 3.11-2.

Table 3.11-2 Impact Description Criteria for Visual Aesthetics

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency
positive: change in landscape to more natural appearance **negative**: change in landscape to less natural appearance	**negligible**: no measurable effect on visual aesthetics **low**: key viewpoints allow distant or minor views of project effects **moderate**: key viewpoints allow direct but not overwhelming views of project effects **high**: key viewpoints allow for close-in, overwhelming views of project effects (views representing a large proportion of the visible landscape)	**local**: effect restricted to the LSA **regional**: effect extends beyond the LSA	**short term**: <3 years **medium term**: 3 to 30 years **long term**: >30 years	reversible or irreversible	**low**: views occur rarely **medium**: views occur intermittently **high**: views occur continuously

3.11.5.3 Mitigation

Visual effects within the corridor to the tailings facility will be minimized with the placement of all linear developments in a single corridor, placing this corridor over an existing road route, and by burying the tailings pipelines along the corridor. Disturbed areas will be revegetated rapidly following construction.

Vegetated buffers will be maintained around the perimeter of the tailings facility site. Earth-dam surface areas that are not to be built up further will be revegetated as soon as feasible.

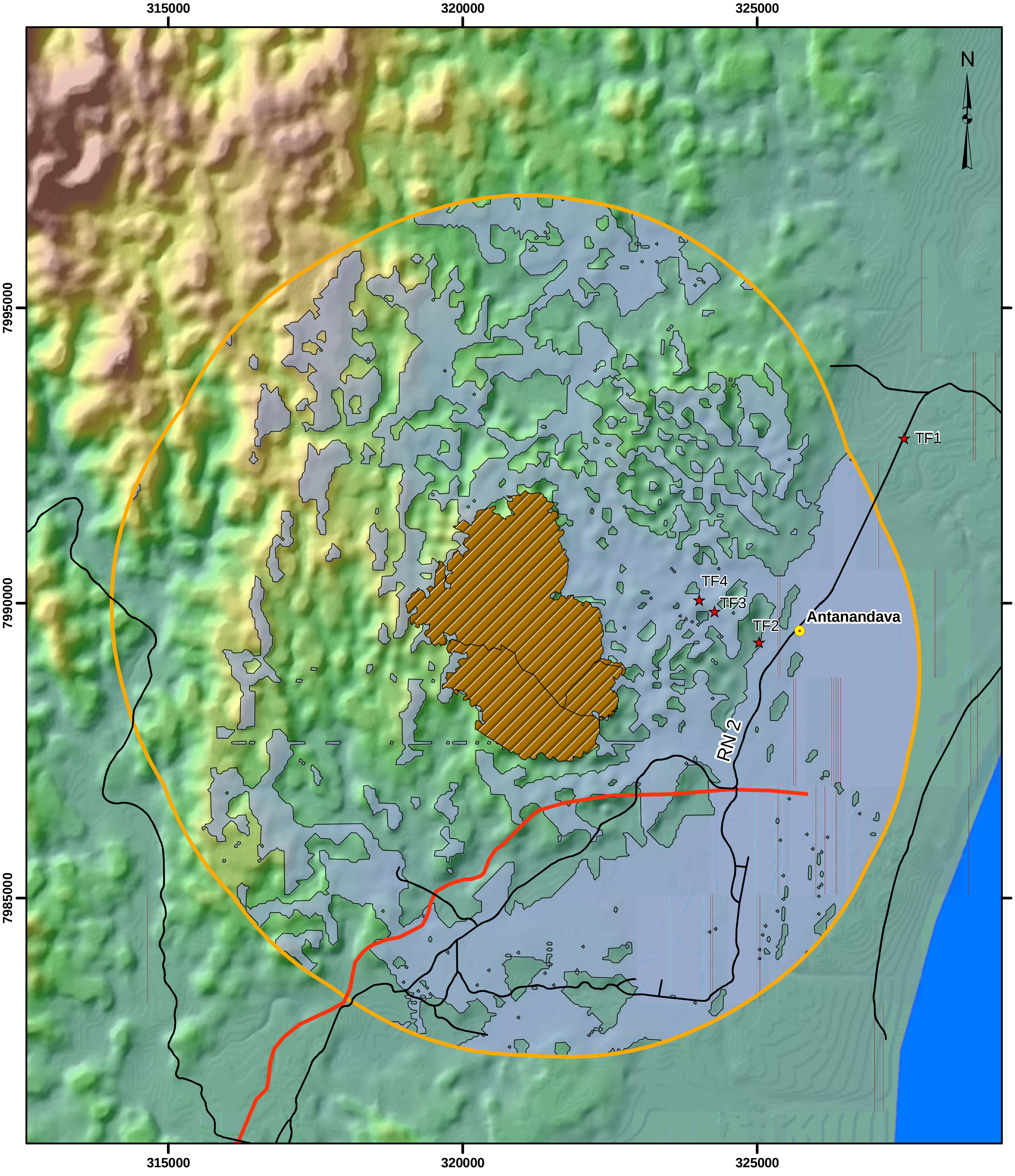
At closure, project buildings will be decommissioned and any waste from these facilities will be properly disposed.

At closure phases, full reclamation will occur. Slope design and erosion control along the slopes around the tailings facility will minimize both short and long-term erosion. Revegetation with native species or other species appropriate to local land uses will allow the affected landscape to blend with the surrounding areas. The surface of the tailings area will be revegetated as soon as feasible.

3.11.5.4 Results

A viewshed evaluation for the tailings facility topography at its maximum extent (27 year snapshot) is presented in Figure 3.11-1. The viewshed evaluation shows that relatively large parts of the study area are within the tailings facility viewshed to the east, while only a few hilltops are within the viewshed to the west.

The viewshed shown is conservative in that it does not incorporate consideration of vegetation or other features which may obstruct views in some areas. For example, it is clear that most areas along Route National (RN) 2 will not provide good views of the tailings facility because of the extent of forest vegetation along the west side of the road. However, based on this analysis, much of RN2 is within the topographic viewshed. Based on the conservative viewshed presented, 45% of the LSA affords views of the project, including valley areas downstream of the tailings facility and areas along the flat coastal plain to the southeast.



LEGEND

- POPULATION CENTRE
- VIEWPOINT
- ROAD
- APPROXIMATE SLURRY PIPELINE ROUTE
- TAILINGS FACILITY
- VIEWABLE AREA
- VISUAL AESTHETICS STUDY AREA

1.5 0 1.5 3

SCALE: 1:90,000 KILOMETRES

REFERENCE

Datum: WGS 84 Projection: UTM Zone 39S.

PROJECT

AMBATOVY PROJECT

TITLE

TAILINGS FACILITY VIEWSHED ANALYSIS

Golder Associates
Calgary, Alberta

PROJECT No. 03-1322-172			SCALE AS SHOWN	REV. 0
DESIGN	GJ	13 Sep. 2005	**FIGURE: 3.11-1**	
GIS	TN	25 Oct. 2005		
CHECK	GJ	09 Feb. 2006		
REVIEW	DM	09 Feb. 2006		

I:\2003\03-1322\03-1322-172\mxd\Visual\tailings_viewshed_8x11_Oct25.mxd

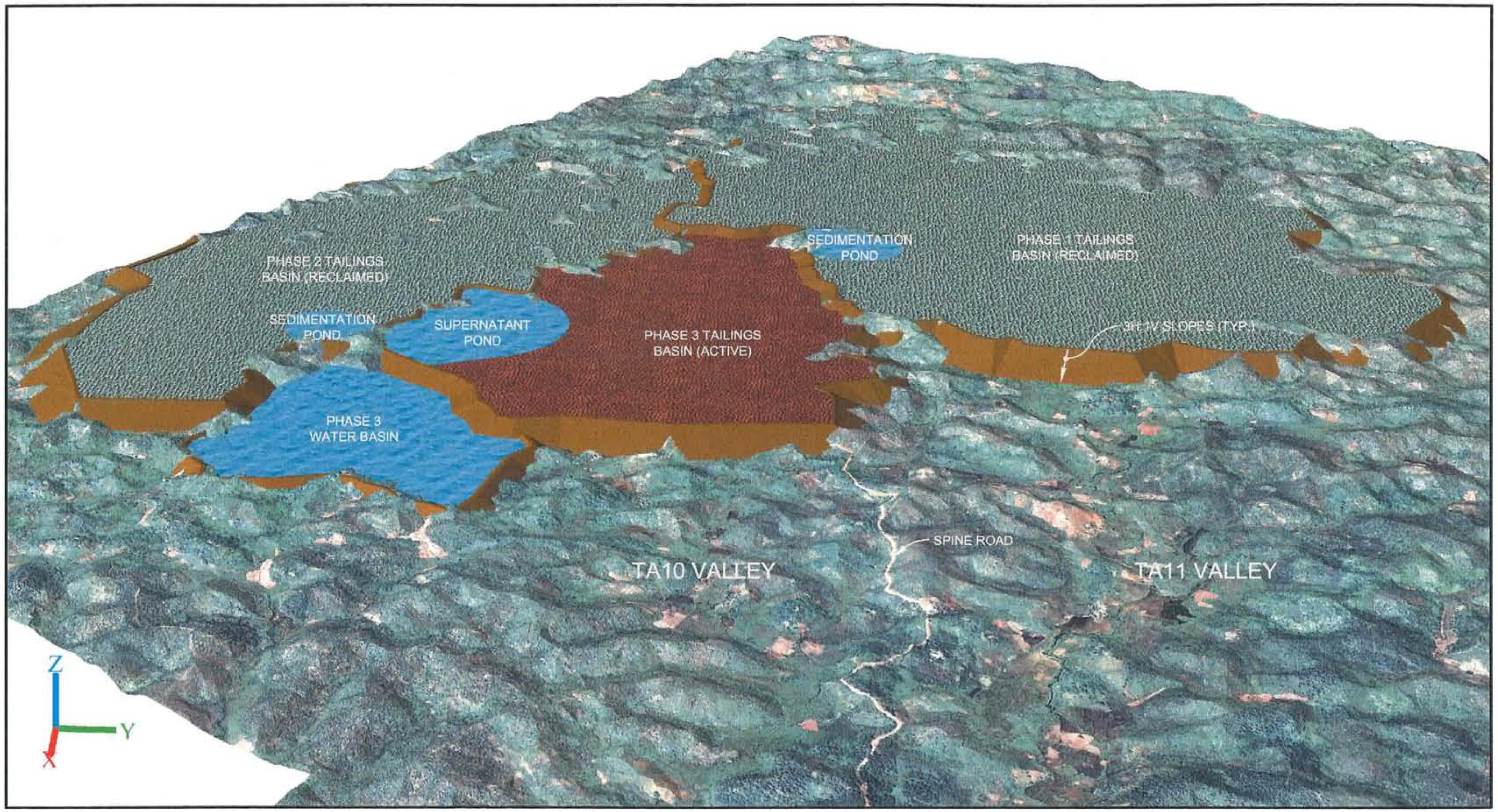
Groups of people likely to be viewing the tailings facility include local residents and passers-by along RN2. For viewers within the viewshed, perceptions of the aesthetic effects of the tailings facility will be determined by:

- the surrounding landscape, including landforms, vegetation, and general level of modification;
- the form, texture, colour, size and level of contrast of the part of the tailings facility being viewed with the surrounding landscape;
- the distance between the observer and the tailings facility;
- viewing orientation, frequency and duration; and
- viewer perception as to what is attractive or unattractive, and expectations as to what "should" or should not be seen in this location.

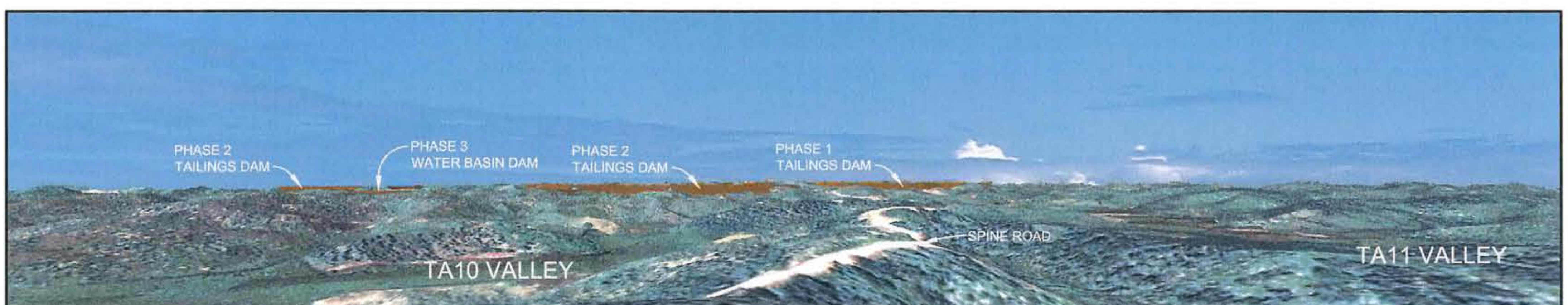
The tailings facility, by year 27, will cover 9.8 square kilometres, including affected pond areas and locations of dam structures. Some additional disturbances will occur within the tailings facility property boundaries around the facility itself (within a total property area of 12.7 km^2). Infrastructure at the edge of the facility will include a pump station and an electrical station. Dam structures will present a large contrast to surrounding slopes, especially during operations, as most will be built up gradually and will not be immediately revegetated.

An overhead view of the future topography of the tailings facility is presented in Figure 3.11-2.

The predicted view from viewpoint TF3 (Table 3.11-1) is presented in Figure 3.11-3. This viewpoint is in an area accessible to local residents as well as visitors who travel just off the RN2 along the access road toward the tailings facility. The view is directed toward the tailings facility, and shows that small parts of the tailings facility topography will be visible in the distance, mainly in areas south of the ridge road. The east-facing dams of the phase 1 tailings basin, phase 2 tailings basin and phase 3 tailings basin are the most visible features of the tailings facility. These features will in reality, be less visible than shown in Figure 3.11-3, because the effect of vegetation in obscuring views is not considered in this figure.



AERIAL VIEW LOOKING WEST



PERSPECTIVE VIEW LOOKING WEST ALONG SPINE ROAD

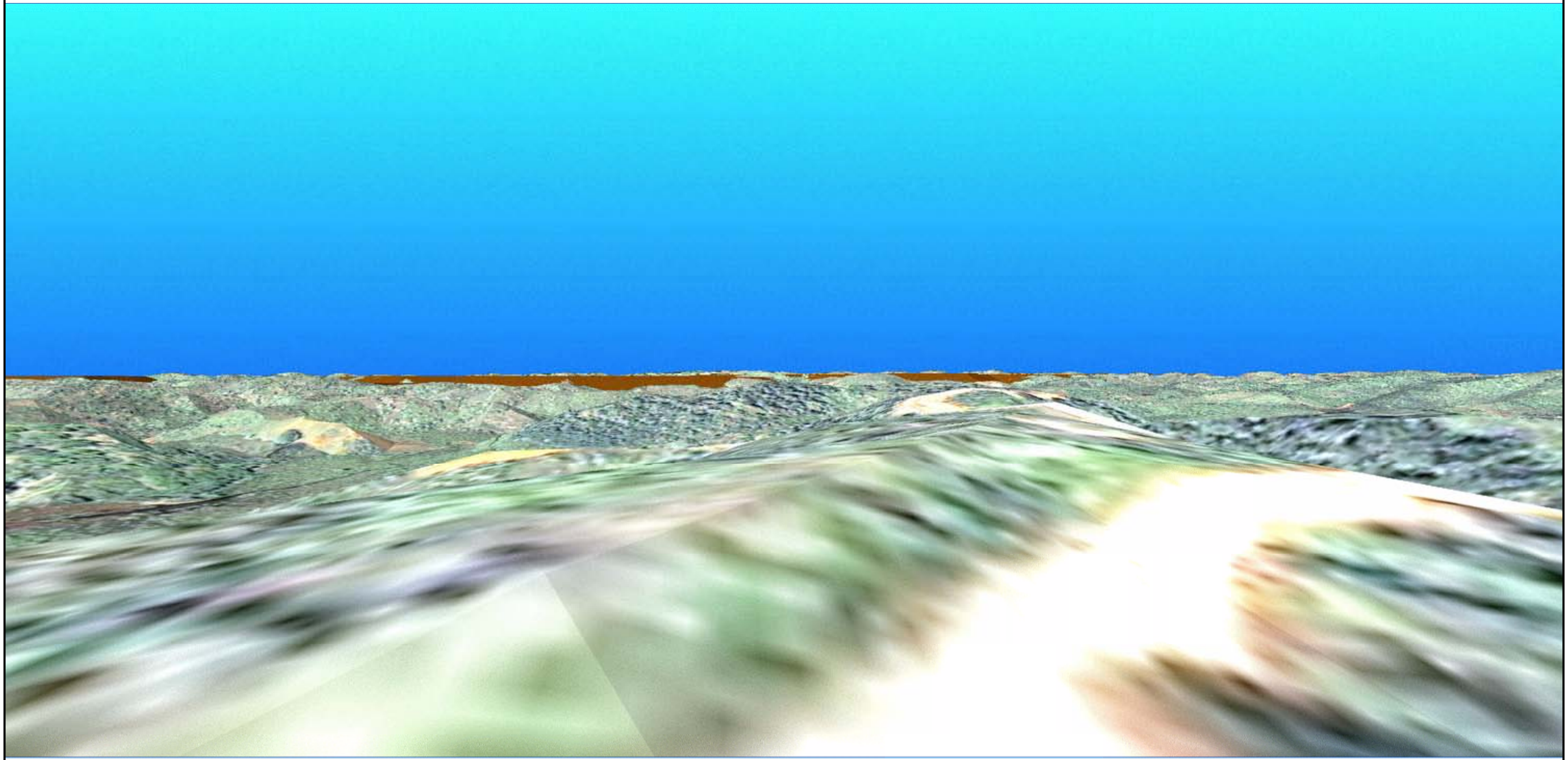
LEGEND:

- RECLAIMED AREA
- EMBANKMENT
- TAILINGS
- WATER

AMBATOVY PROJECT

VISUAL PRESENTATION FOR TAILINGS AREA
YEAR 27 – END OF OPERATIONS

Knight Piésold CONSULTING	P/A NO. NB301-00116/4	REF. –	REV. –
	FIGURE 3.11-2		



PROJECT

AMBATOVY PROJECT

TITLE

VIEW WEST FROM VIEWPOINT TF3 AT YEAR 27 OF OPERATIONS

Golder Associates
Calgary, Alberta

PROJECT No. 03-1322-172			NOT TO SCALE	REV. 0
DESIGN	GJ	13 Sep. 2005	**FIGURE: 3.11-3**	
GIS	TN	25 Oct. 2005		
CHECK	GJ	09 Feb. 2006		
REVIEW	DM	09 Feb. 2006		

3.11.5.5 Impact Analysis

Residual Impacts

Following mitigation, the residual effects during each project period are summarized in Table 3.11-3.

Table 3.11-3 Potential Effects and Residual Impacts for Visual Aesthetics

Project Period	Potential Effects	Mitigation	Residual Impacts
construction and operations	clearing of land and changes in landforms	progressive reclamation of dams where possible	moderate magnitude modification of visible landscape from key viewpoints
	visible facilities and machinery	few facilities; location of activity will be visible to small number of local residents	negligible impact on key viewpoints
	lighting	fully shielded lights directed away from viewers	negligible impact on key viewpoints
	visible emissions and dust	dust control measures	negligible effects
closure	changes in landforms will persist beyond closure	contouring and revegetation of landforms to a natural appearance	moderate magnitude / long-term modification visible landscape
	visible facilities and machinery	decommissioning and removal of facilities and machinery	none

The construction of linear access infrastructure, buildings at the tailings facility and dam structures will occur during the construction phase. During the operations phase, dams will be gradually built up as tailings are deposited into the pond. Among the tailings facility features that may be visible are the widened access corridor and the dam structures. The flat-topped tailings facility resulting after closure and reclamation will continue to contrast visually with the surrounding topography for an indefinite time.

The magnitude of landform visual impacts is considered moderate during construction and operations phases of the project but will be low following full reclamation at closure. The geographic extent of impacts is local, as rough topography obscures the views of most areas outside the LSA. Landform impacts are not reversible, as the landscape will not be returned to its initial state. Viewing frequency is low, as relatively few viewers are expected to be in the areas from which the project will be visible. Overall, the environmental consequence for visual effects is low for the construction, operation and closure phases.

The presence of buildings will have an impact negligible in magnitude, since such facilities will be relatively small and difficult to see from surrounding key viewpoints. Effects are local in extent, medium-term in duration (during construction and operations only) and are reversible. Viewing frequency is expected to be low due to the low number of viewpoints from which the facilities will be visible. The overall environmental consequence of buildings for visual aesthetics will be negligible.

Light release will have an impact negligible in magnitude, due to mitigation and the use of fully shielded lighting fixtures that will not release a great deal of light upward or toward nearby houses or villages. Effects are local in extent, medium-term in duration (during construction and operations only) and are reversible. Viewing frequency is expected to be low. The overall environmental consequence of lighting for visual aesthetics will be negligible.

Dust and visible emissions will be negligible in magnitude. Effects are local in extent, medium-term in duration and are reversible. Viewing frequency is expected to be low. The overall environmental consequence of emissions is low.

An overall residual impact classification for visual aesthetics for each key issue and each phase of the project is presented in Table 3.11-4.

Table 3.11-4 Residual Impact Classification for Visual Aesthetics

Phase	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Issue: Effect of Tailings Facility Landforms on Visual Aesthetics							
construction / operations	negative	moderate	local	medium-term	no	low	low
closure	negative	low	local	long-term	no	low	low
Issue: Effect of Buildings at Tailings Facility on Visual Aesthetics							
construction / operations	negative	negligible	local	medium-term	yes	low	negligible
Issue: Effect of Light Pollution on Visual Aesthetics							
construction / operations	negative	negligible	local	medium-term	yes	low	negligible
Issue: Effect of Visible Emissions and Dust on Visual Aesthetics							
construction / operations	negative	negligible	regional	medium-term	yes	low	negligible

Prediction Confidence

The baseline status of topography in the LSA is well understood, and detailed information about the future landscape at the tailings facility has been made available through project descriptions and closure planning. The closure landscape has been treated conservatively and is expected to represent an impact to visual aesthetics even after reclamation is completed. Overall, the prediction confidence for this assessment is considered high.

Monitoring

No monitoring is proposed specifically for visual aesthetics. Monitoring of the effectiveness of erosion control measures and reclamation success, which have important implications for visual effects, are described in Volume E, Section 6.

3.11.6 Conclusions

The tailings facility will have low environmental consequences for visual aesthetics as a result of modifications to landforms over the long term (continuing following closure). Impact magnitude is greater (moderate) during construction and operations, but because the construction and operations period is only medium-term in length, landscape effects over this period are also low in environmental consequence.

Negligible effects for visual aesthetics will occur due to dust and visible air emissions, lighting and the presence of buildings.

4.1 FLORA

4.1.1 Introduction

This section of the Environmental Assessment (EA) provides an evaluation of potential effects of the Ambatovy Project (the project) on flora within the tailings facility local study area (LSA). In compliance with the Terms of Reference (Volume H, Appendix 1), site-specific data were collected to address the following elements as they relate to flora within the project area:

- map and describe the baseline flora of the study area;
- inventory the natural plant communities of concern to assess species endemicity (including local endemics);
- discuss the mitigation and compensatory mechanisms to be used to reduce/offset losses to flora and natural community types;
- assess residual impacts to flora from construction, operation and closure activities; and
- provide details on flora monitoring and management that include participation of stakeholders.

4.1.2 Study Area

The tailings facility LSA is shown in Volume J, Appendix 1.1, Figure 1-17. This area includes the tailings facility property, the access corridor from the main highway to the tailings facility, and a 500 m buffer around both of these areas.

4.1.3 Baseline Summary

The following provides a summary of the baseline flora results within the tailings facility LSA. The summary focuses on those results that are important for assessing impacts from the project. A complete description of the baseline methods, analysis and results are located in Volume J (Appendix 1.1).

4.1.3.1 Vegetation Overview

The system of west-east running watersheds identified for the potential tailings facility is composed of a heterogeneous, secondary vegetation matrix influenced by an array of human-induced disturbances. The range of habitats within the tailings area includes:

- multi-species agro-forestry systems and home gardens;
- self-regenerating tree plantation and woodlots;
- second-degree regeneration of slash and burn (savoka);
- first-degree regeneration of slash and burn (old tavy);
- active slash and burn field (tavy);
- rangeland with differential degrees of residual plant cover;
- fire-degraded, overgrazed rangeland;
- wetlands; and
- rice paddies.

Due to the disturbed nature of the study area, many species within the LSA are invasive and common within the region. These invasive species have had an impact on the make-up of native plant communities that once existed here.

4.1.3.2 Vulnerable, Threatened and Endangered Species

One International Union for the Conservation of Nature (IUCN) species (*Dalbergia baroni)* was identified within the tailings facility LSA. It is listed as vulnerable but is a widespread species in Madagascar exploited for its valuable wood.

4.1.3.3 Species Endemism

Of the 169 species identified during the flora survey of the proposed tailings facility, 112 are currently classified as endemic to Madagascar and 53 as regionally endemic. No species were listed as local endemics.

4.1.4 Issue Scoping

The following issues related to project impacts on flora were based on the outcome of the public consultation sessions, a review of previous environmental assessments for resource developments in Madagascar and elsewhere, and the Terms of Reference (Volume A, Section 6; Volume H, Appendix 1). The main issues of concern relating to flora within the tailings facility LSA are:

- loss or alteration of plant communities;
- impact to wetlands or wetlands function; and

- invasion of areas containing native vegetation by exotic or unwanted species.

Throughout the EA, key questions were used to develop cause and effect pathways (Volume A; Section 7). The diagram illustrating the pathways between project activities and effects on flora are shown in Volume H, Appendix 9. The key question for flora is:

Key Question FL-1 What Effect Will the Tailings Facility Have on the Loss or Alteration of Plant Communities?

Project-related activities anticipated to result in changes to flora include construction and operation of the tailings facility, and site reclamation at closure. Direct losses to plant communities will result from tailings facility construction and operation activities. Positive effects to flora are expected as a result of closure activities. All project-related effects to flora may have implication for visual aesthetics, land use, fauna and biodiversity.

Concentrations of copper, manganese and zinc in surface and groundwater were predicted to increase above South African water quality guidelines for aquatic ecosystems during operations (Volume E, Section 3.10). These guidelines are not specifically designed to assess effects on wetlands vegetation; however, they do provide general biological benchmarks from which to base the assessment. The change in concentration levels over baseline conditions has potential implications for wetlands vegetation health and community structure.

The types and concentrations of substances within surface water or sediment as a component of a wetlands ecosystem are important to vegetation health because plants within this environment obtain nutrients directly and indirectly from these sources. Rooted aquatic plants that live beneath the water surface are capable of absorption of substances from both the water column and the sediments, while emergent aquatic plants uptake substances primarily from sediments (Denny 1972). Heavy metals in the water column can also be adsorbed onto particulate matter, which may be incorporated into bottom sediments, making them potentially available to both emergent and submergent aquatic plants (Muller 1988).

Flow reductions during operations will occur as a direct result of diverting water from the upper watersheds and through the interception of groundwater, downgradient of the tailings embankments.

The issue of potential for species loss (species extirpation or extinction) was considered in the assessment. Results from the reconnaissance aerial and ground surveys showed that the tailings facility LSA is highly disturbed, and contains no habitat unique to the region. The vulnerable species found within the tailings facility LSA is also present in other areas of the region and so it is not threatened with extirpation or extinction as a result of this project. No locally endemic species were found during the flora field survey. This potential impact is not assessed further.

The potential effects of the project on the spread or introduction of exotic or unwanted plant species were considered. However, the LSA is highly disturbed and contains exotic and unwanted plant species that are prevalent throughout the region. Eradicating these plants from the local area during the operation phase and preventing re-establishment during closure is unwarranted.

4.1.5 Key Question FL-1 What Effect Will the Tailings Facility Have on the Loss or Alteration of Plant Communities?

During the construction and operations phases, flora will be directly disturbed through the clearing of vegetation.

4.1.5.1 Assessment Methods

Impacts of the project on the loss or alteration of flora is assessed through changes in the total area of vegetation types. Direct effects relate to site clearing while indirect effects are related to changes in water and sediment quality and hydrology.

Information from Surface Water Hydrology (Volume E, Section 3.8) which includes a discussion on residual impacts as well as predicted changes in runoff and stream flow volumes, were used to help assess the potential impacts to vegetation within the tailings facility LSA. No regulatory guidelines are available for determining vegetation effects based on hydrological changes. Therefore, a qualitative approach was taken.

Information from Water Quality (Volume E, Section 3.10) which includes a discussion on residual impacts as well as predicted changes in surface water, groundwater and sediment quality were used to help assess the potential impacts to vegetation within the tailings facility LSA. Water quality guidelines are available for human health concerns (WHO 2004) and aquatic ecosystems (Department of Water Affairs and Forestry 1996). However, the first edition of the aquatic guidelines is not focused on riparian and wetlands vegetation effects. Thus, methods used to assess the effects to wetlands vegetation are largely qualitative but within the context of these guidelines.

4.1.5.2 Assessment Criteria

Residual impacts were determined based on a classification system that incorporates direction, magnitude, geographic extent, duration, reversibility and frequency of the impact as described in Volume A (Section 7.4). Determination of the overall environmental consequence uses magnitude, geographic extent, and duration. The assessment criteria used for plant communities are presented in Table 4.1-1.

Table 4.1-1 Impact Description Criteria for Plant Communities

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency
neutral: no change[a] in plant communities **negative:** a change in plant communities	**negligible:** no measurable effect on plant communities **low:** <10% change in plant communities **moderate:** 10-20% change in plant communities **high:** >20% change in plant communities	local: effect restricted to the LSA regional: effect extends beyond the LSA	short term: <3 years medium term: 3 to 30 years **long term:** >30 years	reversible or irreversible	**low:** occurs once **medium:** occurs intermittently **high:** occurs continuously

[a] change in structure or composition

4.1.5.3 Mitigation

Mitigations are planned to reduce the magnitude, geographic extent and duration of impacts from the project on flora within the tailings facility LSA. The main areas of mitigation include:

- maximize avoidance of key plant communities through siting design;
- progressive reclamation of disturbed areas;
- adherence to a closure and reclamation plan;
- establishment of a reclamation trials program; and
- consultation with local planners and stakeholders as to end use.

4.1.5.4 Results

Direct Losses to Plant Communities Within the Tailings Facility Local Study Area

Direct losses to disturbed plant communities resulting from construction and operation of the tailings facility will amount to 1,130 ha (45% of the tailings facility LSA) (Table 4.1-2). Of this portion, the non-forest slash and burn/tavy matrix will be the most affected with a loss of 1,060 ha (48% of this class). The next most affected class is agroforest and secondary forest vegetation with a loss of 27 ha (41% of this type). Other disturbed or modified vegetation types affected include 14 ha of wetlands (23%), 10 ha of rice paddies (11%), 4 ha of *Eucalyptus* and other woodlots (9%) and 3 ha of plantation (43%).

Table 4.1-2 Change in Vegetation Type Area as a Result of Site Clearing within the Tailings Facility Local Study Area

Vegetation Type/ Land Use Type	Base Case (ha)	Impact Case (ha)	Change (ha)	Change (%)
Forested Vegetation				
eucalyptus & other woodlots	44	40	-4	-9
plantation	7	4	-3	-43
agroforest and secondary forest vegetation	66	39	-27	-41
forested subtotal	117	83	-34	-29
Non-Forested Vegetation				
marsh herbaceous vegetation/wetlands	61	47	-14	-23
non-forest slash and burn/tavy matrix	2,219	1,159	-1,060	-48
rice paddies	82	72	-10	-12
non-forested subtotal	2,362	1,278	-1,084	-46
Non-Vegetated Class				
village	14	14	0	0
access corridor (road/rail)	18	7	-11	-61
industry (buildings or exploration areas)	14	14	0	0
quarry	3	2	-1	-33
non-vegetated subtotal	49	37	-12	-24
total	**2,528**	**1,398**	**-1,130**	**-45**

Note: Due to rounding, subtotal and totals may not add precisely to expected values.

Indirect Effects to Plant Communities as a Result of Changes in Hydrology and Water Quality

Hydrology

Results of the hydrology impact analysis indicate that stream and groundwater flow leading to local area wetlands will be reduced considerably during the operation phase (Volume E, Section 3.8). During the closure phase, flows are expected to return to near-baseline levels. Flow reductions during operations will occur as a direct result of diverting water from the upper watersheds and through the interception of groundwater, downgradient of the tailings embankments. All excess water will be discharged to the ocean and a portion re-used at the plant (Volume E, Section 3.8).

Reductions in stream and groundwater flows may have an impact on local area wetlands (47 ha) located outside of the tailings facility footprint. The extent to which these flow reductions may affect wetlands function cannot be quantified given the uncertainty regarding the magnitude of water level reductions (as opposed to flow volumes which were modelled). However, if wetlands water levels are significantly reduced either seasonally or annually compared with the normal regime, the structure of herbaceous wetlands plant communities will likely change (Hartog et al. 1989). The structural change may result from increased nutrient availability (i.e., less dilution) and secondarily due to enhanced seed germination of plants on the edge of the wetlands that have been dormant in sediments for years. Reduction in water levels may also favour emergent and woody species over submersed species.

Water and Sediment Quality

Of the water quality substances tested at baseline and modelled for the operation and closure phases within the tailings facility (e.g., see Volume E, Section 3.10) no substances were predicted to exceed World Health Organization guidelines for drinking water (WHO 2004). Using South African water quality guidelines for aquatic ecosystems, concentrations of copper, manganese and zinc in surface and groundwater were predicted to exceed these levels during operations. Copper levels are only marginally above baseline levels, however, and zinc levels only exceed the guidelines in one basin, due to a reduction in surface water dilution of groundwater in the basin rather than direct impact of zinc from the tailings facilities. Copper and manganese concentrations were predicted to exceed the South African guidelines at closure; again at closure, Manganese is the element of greatest concern, while copper is predicted to be only marginally above baseline levels.

For transported sediment, no substances were predicted to exceed the Interim Sediment Quality Guideline (ISQG) values (CCME 2002). For substances where no guidelines exist, predicted concentration level increases between baseline and operation phases were considered to be very small (Volume E, Section 3.10).

Based on these results, the key substance of concern for vegetation health is manganese. Copper and zinc are of somewhat less concern, as increases are expected to be slight. However, all of these metals may be transported by groundwater and then streams from the tailings facility to wetlands within the LSA. A general discussion of the potential effects of heavy metals to wetlands vegetation follows.

Plants require trace amounts of some heavy metals, whereas excessive levels of essential metals (e.g., copper and zinc) can be detrimental to plant health (Hall 2001). The literature indicates that there is a high amount of inherent variation in plant species responses to different types and concentrations of heavy metals in surface water and sediment (Hall 2001; Cheng 2003; MacFarlane Burchett 2002; Marschner 1995). There is also a paucity of information related to the tolerance levels of wetlands plant species present within the study area. Because of these factors, there is a high level of uncertainty regarding the effects these substances may impart upon wetlands vegetation within the tailings facility LSA. However, there is greater confidence in predicted concentration levels of heavy metals entering the wetlands systems. These concentrations were all predicted to be low and below drinking water guidelines. Taking these factors into consideration, the potential effects to wetlands vegetation within the tailings facility LSA during operations and closure periods is expected to be low.

4.1.5.5 Impact Analysis

Residual Impacts

Residual Impacts to Plant Communities From Clearing Activities

Activities related to construction and operation of the tailings facility will result in vegetation losses. However, the types of habitat that occur within the LSA are not unique to the region and the vegetation is either managed (e.g., rice paddies or plantation) or degraded from its original state. Nonetheless, flora within the project footprint (primarily the forested and wetlands vegetation classes) does offer some biological diversity value and wildlife habitat to the local and regional areas.

Within the LSA, 29% (34 ha) of forested habitats and 23% of wetlands (14 ha) will be removed during construction and operation phases. These impacts correspond to a high magnitude of loss. However, these high percentages are largely related to the small buffer used for the LSA around the disturbance footprint. In consideration of the small size of the LSA and due to the lower quality of the vegetation within the LSA, the magnitude of losses is deemed moderate. Direct impacts from the project on the forested and wetlands vegetation classes are predicted to be local in geographic extent and medium in frequency. The duration of effects will be long-term during construction and operation phases, medium-term for the treed class during closure and long-term for wetlands. The effect of the project will be reversible for the forested class and irreversible for wetlands. Residual impacts to rice paddies are discussed within the Land Use section (Volume E, Section 5.3).

Mitigation to limit the amount of disturbances in the LSA has in part been achieved through siting design (i.e., locating the tailing facility in a previously disturbed area). To further minimize the long-term effects of the project on vegetation, reclamation is planned during the closure phase.

The tailings facility will be re-vegetated in stages after each basin is infilled with tailings material and soil moisture levels are within an acceptable range for reclamation purposes. The main objectives of the revegetation program include:

- control water erosion on tailings embankments and other steep slopes; and
- revegetate the remaining areas based on guidance from local stakeholders and results derived from the reclamation trials program.

Water erosion control on steep slopes such as on the tailings embankments will be achieved through designed systems and seeding with a self-sustaining seed mix appropriate to the region (see Volume E, Section 6 for additional information on reclamation). A research-based reclamation trials program will be initiated to adequately address the optimal reclamation techniques given the nature of the tailings material.

Given the uncertainty associated with the type of vegetation that will establish during the closure period, a worst-case scenario is assumed for the purposes of this assessment. This scenario states that all woodlots and plantations (7 ha) will be permanently lost from the tailings area. In the place of these forest types, it is assumed that some form of secondary forest vegetation will re-establish. Based on these assumptions and the current general vegetation characteristics (i.e., current vegetation not unique to the region and existing in a degraded or unnatural state), a low environmental consequence is predicted for forest loss.

Table 4.1-3 Residual Impact Classification for Loss or Alterations of Plant Communities

Component	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
losses to plant communities							
forested vegetation types	negative	moderate	local	medium-term	reversible	medium	low
wetlands	negative	moderate to high	local to regional	long-term	irreversible	medium to high	moderate

For loss of wetlands, a moderate environmental consequence is predicted. The impact prediction for wetlands is different than with forest cover types for three primary reasons: 1) wetlands were historically less common in the region than forests; 2) wetlands within the LSA are presumed to have been disturbed to a lesser degree than forests (i.e., less local use of wetlands than forests by locals) (see also Volume E, Section 4.3); and (3) wetlands are difficult to reclaim. These factors add greater value to the wetlands ecosystem types than the degraded or managed forest vegetation types.

Residual Impacts to Wetlands Vegetation

Stream and groundwater flow leading to local area wetlands will be reduced considerably during the operation phase. Flow reductions may cause wetlands water levels to subside, which in turn may affect the structure and composition of the plant communities.

The magnitude of impacts to wetlands vegetation as a result of water flow reduction is conservatively estimated to be high considering the substantial reduction in flow volumes to the wetlands. The extent of effects may extend beyond the LSA due to hydrologic linkages between sub-basins. Effects will occur continuously during the operation phase. Based on these factors and the general disturbed conditions within the LSA, hydrological changes to wetlands vegetation within the tailings facility LSA is predicted to result in a moderate environmental consequence. Water flow will be monitored to ensure these parameters are managed to minimize impacts. Dependent on results, an aquatics vegetation monitoring program using indicator species may be initiated. Residual effects on rice paddies are described in the Land Use section (Volume E, Section 5.3).

The magnitude of potential impacts to wetlands vegetation as a result of changes in water quality is predicted to be low. There is the potential for copper, magnesium and zinc to increase in concentrations in one or more sub-basins during the operation phase, which may in turn affect vegetation health or plant community composition. However, increases in copper and zinc will be very small and all water quality parameters are predicted to be below drinking water guidelines. The extent of potential effects may extend beyond the local area and will occur continuously over the life of the project. Based on these factors, water quality changes to wetlands vegetation within the tailings facility LSA is predicted to result in a low environmental consequence. Water quality will be monitored downstream to ensure levels are managed to minimize impacts. Dependent on results, an aquatics vegetation monitoring program using indicator species may be initiated.

Prediction Confidence

Confidence in impact predictions is related to:

- adequacy of baseline data for understanding current conditions;
- understanding of project-related impacts on the ecosystem; and
- probability of chance events.

Flora impact predictions are based on the spatial distribution of vegetation types within the tailings facility LSA. The baseline vegetation map was developed from a combination of air photograph interpretation and selected ground-truthing. The vegetation type classification is considered to be relatively accurate and therefore the prediction confidence for direct effects on vegetation (i.e., loss of vegetation types) is considered to be high.

There are gaps of scientific knowledge regarding the potential effects of water levels and water quality changes to wetlands vegetation. Models used to predict these changes also have limitations. However, predicted changes to flows and water quality are quite well understood. Thus, prediction confidence of residual impacts to wetlands is considered to be medium.

Last, catastrophic events (e.g., extreme cyclones in quick succession) could cause water levels within the tailings facility to overflow and spill possibly toxic waters into the surrounding environment. These would however be highly diluted during such an extreme weather event.

Monitoring

Water flows and quality will be the prime parameters monitored to ensure that water management minimizes impacts on wetlands and water systems. Dependent on results, focused wetland vegetation monitoring could be initiated. A vegetation monitoring program will be implemented to ensure that reclamation efforts are successful and erosion control measures are working effectively.

4.1.5.6 Conclusions

Avoidance of native vegetation through siting design will provide the most effective mitigation to limit native plant community losses. Of the vegetation that will be lost as a result of the tailings facility, the majority is highly disturbed consisting primarily of tavy matrix. Wetlands also exist in the LSA but are disturbed as well. Because of the relatively poor vegetation condition, the environmental consequence to direct losses of plant communities is predicted to low during construction and operation phases. During closure, revegetation of the tailings facility will be carried out to control water erosion and meet stakeholder's goals. A research-based reclamation trials program will be initiated to help ensure that adequate and desired vegetation cover can be achieved at closure.

Indirect effects to plant communities may occur as a result of changes to wetlands water levels and water quality. Hydrologic changes resulting from construction and operation of the tailings facility may alter plant community composition due to reductions in the surface and groundwater flow regimes. All water quality parameters are predicted to be below drinking water guidelines during operations and closure and therefore concentrations are likely too low to cause any adverse affects to wetlands vegetation health.

4.2 FAUNA

The effects of the Ambatovy Project (the project) on fauna in the area of the tailings facility are described in Volume D, Section 4.2. Effects of the tailings facility are evaluated together with the effects of the process plant due to the close proximity of these two developments.

4.3 FISH AND AQUATIC RESOURCES

4.3.1 Introduction

This section presents the Environmental Assessment (EA) of the potential effects of the proposed Ambatovy Project (the project) on fish and aquatic resources in the tailings facility, within the Toamasina study area, and specifically addresses fish communities, aquatic macro-invertebrates and habitat as outlined by the Ambatovy Project Terms of Reference.

The EA presents a summary of baseline survey results and issues, followed by the impact assessment. Detailed aquatic resources baseline reports, including baseline methods, analysis and results specific to this component of the project are located in Volume J, Appendix 3.1, Attachment 1.

4.3.2 Study Area

The Toamasina Aquatics study area (Volume A, Figure 7.2-3) is located south of Toamasina, and includes the tailings facility, the process plant property and associated service corridors and infrastructure for the process plant and tailings, and future bridge location across the Pangalenes Canal. The tailings facility Local Study Area (LSA) falls within the larger Aquatics study area and includes the water bodies within and associated with the three valleys and sub-basins of the Ambolona watershed affected by the tailings facility, and the service corridor between the plant site and the tailings area.

4.3.3 Baseline Summary

4.3.3.1 Methods

Detailed seasonal sampling programs for fish, aquatic invertebrates, aquatic macrophytes and general habitat characteristics were conducted at six stream/river sites in the tailings LSA in 2004 and 2005 (Volume J; Appendix 3.1, Attachment 1, Figure 2). Five sites were located in the Ambolona tributaries; one site was located in an adjoining upstream watershed. A dry season (low flow) sampling was conducted in September-October 2004, and a wet season sampling in January 2005. Sampling sites were distributed within and downstream of the tailings and to encompass drainages likely to be affected by activities associated with the tailings operation.

One stream site sampled for the tailings facility was located on the service corridor (road and pipelines) between the process plant and the tailings facility.

Aquatic Habitat

A detailed habitat characterization based on instream characteristics, including channel width, depth, flow rate, dominant substrate types and cover, was completed to quantify habitat type at each site. In-situ water quality (pH, total dissolved solids (TDS), temperature, dissolved oxygen) was also determined at each site. In addition, the Intermediate Habitat Integrity Assessment (IHIA) model (Kemper 1999) was used to describe and quantify habitat characteristics.

Fish

Fish were collected using a variety of techniques in order to sample all habitat types used by the resident fish species. Electrofishing, seine nets, and gill nets were the primary methods of capture; in addition, cast nets and baited hooks were used in deeper water and to collect food fish for contaminant analysis. Except for voucher specimens retained for confirmation of identification, all other fish were released alive after recording basic life history data (i.e., length, weight, etc.). Preliminary identification to species level was done by the Biology Department, University of Antananarivo. Confirmation of these identifications is in progress by the American Museum of Natural History and the New York Aquarium, and therefore the assessments based on species identifications within the following material are provisional.

Macro-Invertebrates

Aquatic macro-invertebrates were collected using a quantitative (USEPA 1998) and qualitative (Dickens and Graham 2002) approach to ensure collection of community information from all habitats. Representative samples were preserved in 90% ethanol for subsequent identification. Macro invertebrates were identified to the family or genus levels. Similar to the fish fauna, preliminary identification of macro-invertebrates conducted by personnel at the Biology Department, University of Antananarivo is awaiting expert confirmation and species determinations.

Periphyton (benthic algae) samples were collected during the dry season sampling (two sites); these have been archived for future analysis.

Resource Use

Information on the harvesting of fish and invertebrates by local artisanal fisheries was collected on an opportunistic basis by observations or conversations with residents within the areas sampled during field programs.

Information Review and Data Analysis

Published and unpublished literature on the freshwater ichthyofauna and aquatic ecosystems of Madagascar and the project region, conservation status reports on the native fisheries, and local experts were consulted for the report. Multivariate analytical techniques were used to assess the community assemblage of fish and macro-invertebrate field data. Similarly, indices of richness, diversity and evenness were calculated for both groups of organisms to characterize community composition.

4.3.3.2 Results

Aquatic Habitat

Generally, upstream sites in the tailings LSA were small 2^{nd} order streams exhibiting shallow depths, low gradients and low flow rates. Lower sites near the boundary of the drainage basins of sites (larger streams) contained deeper channels and pool habitats. Water bodies in the tailings LSA are weakly acidic with pH ranges of 5.1 to 6.4; water temperatures were within a similar range of 25 to 31°C during both seasons. The most prevalent substrate types were fines and silt and to a lesser extent, gravel and cobbles. Instream cover was site specific, but generally included small woody debris, leaf litter, and overhung vegetation.

Based on the IHIA classification of habitat quality and quantity all sampling sites in the tailings LSA exhibited significant disturbance and loss of natural ecosystem function (IHIA Classes D, E, F; Table 4.3-1). Much of the valley bottom area, and associated stream habitat, within the three drainages has been developed into rice paddies. Major disturbances at these sites include 1) replacement of indigenous vegetation with exotics, 2) slash and burn (tavy) activities on the valley hillsides, 3) presence of exotic fish fauna, including the predator *Channa maculata* (blotched snakehead), and 4) channel modifications and development of paddies for rice production.

Fish

A combined total of 17 fish species, comprising five endemic, four native, and eight introduced species were collected from the tailings LSA during the low and high flow surveys (Table 4.3-2).

Table 4.3-1 Habitat Characteristics of Sampling Sites in the Tailings Local Study Area

Site	IHIA Class[(a)]	Habitat Description
TMT001	E	Channel modifications with loss of natural biota and ecosystem function. Presence of exotic fish fauna including the predator *Channa maculata*.
TMT002	E	Upstream site in tailings area. Channel modifications with, loss of natural biota and ecosystem function. Indigenous vegetation replaced by exotics.
TMT003	F	Critically modified. Extensive modification of streambed, channel, flow regime, and presence of exotic predator fish *C. maculata.*
TMT004	D	Upstream site in tailings area. Largely modified, considerable loss of natural habitat, biota and ecosystem function. Presence of exotic vegetation.
TMT005	D	Largely modified, considerable loss of natural habitat, biota and ecosystem function. Replacement of indigenous vegetation and presence of exotic fish.
TMT006	D	Wetlands site. Largely modified, loss of natural habitat, biota and ecosystem function. Presence of exotic vegetation and fish.

(a) Based on the IHIA model (Kemper 1999).

Generally, species diversity was moderately high (range seven to eight species) at all sites but abundances were low except for two species each of endemics (Bedotia madagascariensis and Sauvagella madagascareinsis) and exotics (Oreochromis macrochir and Tilapia zilli). The high total abundance (all species) occurred at sites TMT001 and TMT003, and may be associated with higher heterogeneity in habitat type (larger streams, increased instream cover). Although no clear pattern emerged between diversity and habitat characteristics, significant temporal difference in species association and abundances was observed between high flows and low flows at, at least three sites (TMT003, TMT005 and TMT006), suggesting some seasonal movement or migration within the watercourses.

Most of the fish found in the streams were relatively small-bodied species, and were not highly used locally for food fish. However, among the exotic food fish species, *Tilapia zilli* was collected (in high abundances) at all sampling sites in the tailings LSA. Other common exotics used locally as food fish were *Tilapia rendalli*, *Osphronemus goramy,* and *Oreochromis niloticus*. Potential food fish included the *Anguilla* (eel) species and the snakehead; but information was not obtained on their use. Some local use is made of smaller species (*Bedotia madagascarensis*) captured in reed traps.

Table 4.3-2 Fish Species Recorded in the Tailings Local Study Area During 2004-2005 Surveys

Family	Species	Origin	Conservation Status[a]	IUCN Status[b]
Ambassidae	*Ambassis fontoynonti*	E		DD
Anabantidae	*Ctenopoma ansorgii*	I		
Anguillidae	*Anguilla bicolor*	N	S	nl
Anguillidae	*Anguilla marmorata*	N	S	nl
Anguillidae	*Anguilla mossambica*	N	S	nl
Bedotiidae	*Bedotia madagascariensis*	E	T	NT
Clupeidae	*Sauvagella madagascariensis*	E		nl
Cichlidae	*Oreochromis macrochir*	I		
Cichlidae	*Oreochromis niloticus*	I		
Cichlidae	*Tilapia zilii*	I		
Cichlidae	*Tilapia rendalli*	I		
Eloetridae	*Hypseleotris tohizanae*	E	U	nl
Eloetridae	*Ophiocara macrolepidota*	E	U	nl
Gobiidae	*Glossogobius giuris*	N	S	nl
Ophicephalidae	*Channa maculata*[c]	I		
Osphronemidae	*Osphronemus goramy*	I		
Poeceliidae	*Xiphophorus maculatus*	I		

(a) Sparks and Stiassny (2003).
(b) IUCN Red List (2004).
(c) Misidentified as Ophicephalus striatus.
Note: E = endemic, I = introduced, N = native; S = secure, T = threatened, U = unknown; IUCN status: nl = not listed, DD= data deficient, NT = near threatened.

Aquatic Macro-Invertebrates

A total of 55 macro-invertebrate taxa were recorded in the tailings LSA during the 2004-2005 survey (Table 4.3-3). No clear distributional pattern was present for number of taxa or diversity between the sites in the LSA, but the community analysis indicated a seasonal change in density and abundance. The family *Chironomidae* (midges) was the most abundant taxa present during the low flow survey; the family *Atyidae* (freshwater shrimp) was the most abundant taxa at sites surveyed during the high flow survey. The highest total number of taxa, species richness and density of invertebrates was recorded at the wetlands site TMT006, during the high flow survey.

Many freshwater invertebrates are used locally as food. These include several crustaceans (freshwater shrimp) and gastropods.

Table 4.3-3 Aquatic Invertebrate Taxa from the Tailings Local Study, 2004-2005 Survey

Order	Family	Order	Family
ARHYNCHOBDELLIDA	Hirudidae	*HEMIPTERA*	Aphelocheiridae
COLEOPTERA	Dysticidae		Corixidae
	Elmidae		Gerridae
	Gyrinidae		Hydrometridae
	Helophoridae		Mesoveliidae
	Hydrophilidae		Naucoridae
	Scarabidae		Nepidae
			Notonectidae
DECAPODA	Atyidae		Veliidae
	Grapsidae		
	Palaemonidae	*LEPIDOPTERA*	Pyralidae
	Potamonautidae	*MEGALOPTERA*	Sialidae
		ODONATA	Aeshnidae
DIPTERA	Athericidae		Calopterygidae
	Ceratopogonidae		Coenagrionidae
	Chironomidae		Corduliidae
	Dixidae		Gomphidae
	Empididae		Libellulidae
	Simuliidae		Platycnemudidae
	Tipulidae		
		OLIGONEURIIDAE	Ephemeridae
EPHEMEROPTERA	Baetidae		
	Caenidae	*TRICHOPTERA*	Beraeidae
	Ephemerellidae		Ecnomidae
	Heptagenidae		Hydropsychidae
	Leptophlebidae		Leptoceridae
	Oligoneuridae		Polycentropodidae
	Polymitarcidae		Psychomyiidae
GASTEROPODA[(a)]	Bithyniidae		
	Bythinellidae		
	Hydrobiidae		
	Planorbidae		
	Thiaridae		

(a) Class.

Endemic and Native Species

Fish

The fish fauna within the tailings LSA contains five endemic fish species (*Ambassis fontoynonti, Bedotia madagagascariensis, Hypsleotris tohizanae, Ophiocara macrolepidota* and *Sauvagella madagascariensis*).

Of the endemic species, *B. madagascariensis* was the most abundant and during the low flow survey exhibited the highest abundance of all fish species captured at the five sample sites within the Ambolona basins. *B. madagascariensis* is listed as “Near Threatened” in the IUCN Redlist 2004. The genus *Bedotia* exhibits a high incidence of single-basin endemism. It has been reported to prefer almost exclusively clear, silt-free habitats (Loiselle and Stiassny 2003) and its relatively high abundance in the disturbed habitats of the tailings area is therefore intriguing. Although a small bodied fish, it is captured in reed-traps throughout the region, as a food item.

Sauvagella madagascarensis was present at two sites and was the most abundant fish at site TMT001 during the high flow survey. This endemic species is restricted to eastern coastal drainages, mostly in forested small rivers and streams, but also occasionally in brackish waters, and the populations appear to be stable (Stiassny 2003). It is not IUCN listed.

Ambassis fontoynonti, was present in small numbers at three of the six sites. It is listed as DD (data deficient) by the IUCN Redlist.

Both of the other two endemics, *Hypsleotris tohizanae* and *Ophiocara macrolepidota,* were present in small numbers at some of the sample sites. They are not listed by the IUCN, but little is known of their range or populations.

Four native fish (*Anguilla mossambica, A. Bicolor, A. marmorata* and *Glossogobius giurus*), were also recorded in the tailings LSA.

Macro-Invertebrates

Several endemic aquatic invertebrate taxa are present in the streams within the LSA, however the current level of identification limits the description of taxa; several of the significant groups found in the LSA samples are:

- The *Atyidae* (freshwater shrimp) have a high degree of endemism (77%), with 26 species in four genera existing on the island (Raharivololoniaina 2004). Within the LSA, they were abundant during the wet season survey, with one genera (*Caridina*) and two undetermined species collected. *Atyids* (locally known as *patsa*) are small shrimp (generally less than 35 mm in length) but in eastern coastal areas are captured, dried and used as food (Short and Doumenq 2003).

- The Odonata family (dragonflies) *Aeschnidae* was also common during the wet season, during the survey two species belonging to an undetermined genera were collected. Madagascar is one of four smaller islands in the world noted for their rich *Odonata* fauna and the number of endemic species and genera are remarkable (Raharivololoniaina 2004). Of 52 genera, 12 are endemic; of the 181 named species and subspecies, 132 are endemic (Donnelly and Parr 2003).

Important Aquatic Habitats

Important aquatic habitats and ecosystems identified in, or in association with, the Toamasina area are the natural wetlands and upper tributaries which contained forested hillsides and remnant riparian forest/vegetation with lower amounts of impact from agriculture (slash and burn; water diversion).

The streams and rivers within the tailings disturbance area contain the headwaters of three sub-basins of the Ambolona watershed. They are located in a series of three valleys, characterized by moderately steep forested hillsides, and flat, wet, valley floors (Volume E, Section 3.1 Topography and Geomorphology). A majority of the tailings disturbance area contains small 1^{st}, 2^{nd} and 3^{rd} order streams. The two sample locations within the tailings footprint (TMT002 and TMT004) were located on 2^{nd} order streams. Many of the 1^{st} order streams originate on the steep valley slopes, either from seasonal surface flow or groundwater.

The majority of the 1^{st} order streams may only be accessible to fish at the bottom of the reach and confluence at the 2^{nd} order stream; however they will be used by aquatic macro-invertebrate species and periphyton algal species adapted to the flow regime and channel morphology. Some of these areas are not be totally cleared for agriculture and maintain higher water quality.

The 2^{nd} order stream sites contained a fish fauna generally dominated by endemic (*Bedotia madagascariensis* – IUCN listed as Near Threatened and *Ophiocara macrolepodia*) and native species, but with the several exotics also present. However, the downstream sites at the bottom of the drainages also contained populations of these endemics and the significance or importance of these upstream habitats is unclear. The high relative abundance of *Bedotia* in the drainage would suggest that sufficient suitable habitat refugia exist for it to maintain viable populations in the presence of exotic species. Two native species

(*Anguilla bicolor* and *A. marmorata*) were collected in the study area only at TMT002 during the high water, likely in response to the availability of riffle habitats. These species spawn at sea and use freshwater habitats principally for feeding.

Occasional wetlands or marshes which are not severely disturbed remain in the area. These habitats are important as they generally have a high biodiversity of aquatic fauna, and are likely important for their role in maintaining and regulating water levels and water quality in the systems. Site TMT006 was located in a large, intact wetlands, and although the habitat integrity was affected by surrounding land use and the invasion of exotics, it retained a high diversity of fish and aquatic invertebrate taxa.

4.3.4 Issue Scoping

4.3.4.1 Issues and Key Questions

Although the tailings area is extensively man-modified, consultation recorded a concern that biological resources not be heavily impacted by the project (Volume A, Section 6). The primary issues identified with respect to the potential impact of the project on the aquatic biota and environment in the tailing facility area are:

- Loss of fish habitat (riparian vegetation canopy food source, instream habitat and invertebrate communities) and impairment of stream water quality (sedimentation) as a result of disturbance associated with clearing and development of the tailings facility and ancillary facilities (service roads and pipelines).
- Loss of locally endemic fish or aquatic invertebrate populations as a result of the total removal or disturbance of aquatic habitat in streams and wetlands during tailings facility construction and operation.
- Alterations to stream flow (increased or decreased runoff to downstream water bodies) below the tailings facility affecting the life history of fish and aquatic biota, and critical habitat functions.
- Water quality changes during construction and operation of the tailings facility affecting the health, abundance and survival of endemic fish and aquatic fauna in downstream drainages.
- Effects on harvest of local fish or invertebrates (crustaceans or molluscs).
- The effectiveness of post-closure aquatic habitat and biota reclamation or compensation.

These issues and impacts have been addressed in the following key questions:

Key Question FA-1 What Effect Will the Project Have on Aquatic Habitat?

Key Question FA-2 What Effect Will the Project Have on the Abundance of Aquatic Biota and Survival of Endemic or Native Species?

Key Question FA-3 What Effect Will the Project Have on Artisanal Fisheries?

Impacts to aquatic resources could occur during construction, operations and closure of the tailings facility, as illustrated in the linkage diagram (Volume H, Appendix 9).

4.3.4.2 Assessment Parameters

Aquatic biota of significance includes both the fish and invertebrates that form part of the aquatic ecosystem in the Toamasina area. By association, the aquatic habitats that these organisms depend on to complete their life history are also a critical part of the aquatic ecosystem.

For this assessment, species of concern, important ecosystem groups and locally important habitat types were examined during the impact assessment and development of mitigation strategies. The selected groups and habitats for the tailings area are:

- endemic fish species;
- macro-invertebrate communities (containing endemic or native species);
- tailings area stream habitats (1st to 4th order streams); and
- food fish or invertebrate food sources used by artisanal fisheries.

Measurable parameters used for the assessment of fish and aquatic resources are summarized in Table 4.3-4. As the level of available information from the baseline, literature or local specialists did not always allow a quantifiable assessment, qualitative evaluations based on professional judgments were also used.

Table 4.3-4 Ecosystem Components, Parameters and Criteria for Fish and Aquatic Resources

Question	Ecosystem Component	Measurable Parameter	Evaluation Criteria
change in the quality and availability of aquatic habitat	headwater streams, endemic fish, aquatic macro-invertebrates	stream order and exclusion length water flow and prediction fish habitat based on estimated area reclamation habitat type	loss of fish habitat water quality and suspended sediment guidelines qualitative assessment of long-term changes to aquatic biota community structure
change in abundance of aquatic biota, survival of endemic species and aquatic community structure	endemic and native fish, benthic macro-invertebrates	fish / invertebrate community structure and diversity results of physical habitat and aquatic health assessments tailings operations and discharge water intake operation	subjective evaluation of sustainability of the resource; professional judgment conservation status (IUCN 2004 and published checklists) intake screening guidelines (i.e., Canada DFO 1995) water quality guidelines for the protection of aquatic life (CCME 1999)
change in fish health, quality and use	locally harvested fish or invertebrates	surface water quality and prediction local harvest metal concentrations in baseline fish tissue predicted fish abundance	environmental health and safety guidelines for precious metal mining (IFC 2004) suggested values from the literature subjective evaluation and professional judgment

Use was also made of the conclusions of the surface water, groundwater, water quality investigations and the preliminary design for the tailings and service corridors.

4.3.5 Key Question FA-1: What Effect Will the Project Have on Aquatic Habitat?

4.3.5.1 Impact Pathways

Aquatic habitat can be affected by activities in the study area during construction, operation and closure phases. These habitats can also be affected by ancillary facilities and services such as watercourse crossings by access roads. Changes in the availability, quality or quantity of aquatic habitat will result from:

- removal or disturbance of aquatic (riparian and instream) habitat;
- changes in water flow downstream; and
- changes in surface water quality.

Removal and Disturbance of Aquatic Habitat

Clearing of riparian vegetation and disturbance of the riparian zone results in an indirect loss of aquatic habitat through alteration and loss of terrestrial food sources for aquatic biota, and changes to physical limnology (e.g., water temperatures) and water quality (e.g., sedimentation) affecting the ability of biota to survive or complete critical life history functions. Riparian clearing will occur during construction of the tailings area and the service corridors.

Removal and drainage of existing stream channels and wetlands (either permanent or ephemeral) permanently eliminates the instream habitats by directly removing water flows and channel geometry, and eliminates the capability of the local watersheds to support fish and other aquatic biota. Loss and disturbance of these habitats will occur during the tailings facility construction. Creation of the tailing facility berms also block access to upstream habitat which may be critical to life history function of some fish. Disturbance will also occur during watercourse crossings associated with access road construction, pipeline construction, and the water intake construction.

Changes in Water Flow Downstream

Change in water flow (surface water or groundwater) will occur, as during construction and operation, headwater streams will be disturbed and a portion of the water collected or diverted, or the drainage area eliminated. These changes can affect the use of downstream habitats by aquatic biota.

Changes in Surface Water Quality

Changes to surface water quality (i.e., sediments, temperature and contaminants) will occur as a direct result of runoff from tailings site clearing, erosion from the berms, riparian vegetation removal and effluent management of the process tailings. Water quality may also be affected by instream activities during construction of ancillary facilities (roads, pipelines) and by local air quality. These changes may directly or indirectly affect fish and aquatic biota, and the productivity of aquatic habitat.

4.3.5.2 Assessment Methods

Aquatic Habitat

The linear value of stream channels or wetlands, by order, lost to the footprint of the tailings facility and channels disturbed (i.e., fragmented or flows directly altered) was determined by geographic information system (GIS) measurement of Landsat images and mapped data. Habitat types and integrity, fish species and associated invertebrate species as determined in the baseline were identified and impacts discussed; estimates of wetted habitat area lost were made based on extrapolation of mean measurements or estimates at field sample sites. Disturbance and alteration of aquatic habitat along the access road and pipeline routes was assessed from map data and enumeration of watercourse crossings.

Changes in Water Flow Downstream

Changes in water flow downstream were examined for the watershed areas as provided within the Hydrology Section (Volume E, Section 3.8). Impacts on aquatic habitats, fish communities and aquatic invertebrate species identified during the baseline survey were discussed qualitatively.

Changes in Surface Water Quality

Predicted changes in water quality (Volume E, Section 3.10) and hydrology (Volume E, Section 3.8) were examined for the tailings area and the watercourses along the access roads. Impacts on aquatic habitats, fish communities and aquatic invertebrate species identified during the baseline survey were discussed qualitatively.

4.3.5.3 Assessment Criteria

The impact description criteria used to evaluate fish and aquatic resources for all Key Questions are presented in Table 4.3-5.

Table 4.3-5 Impact Description Criteria for Fish and Aquatic Resources

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency
positive, **negative** or **neutral** for the measurement endpoints	**negligible**: no measurable effect on the measurement endpoint **low**: <10% change in measurement endpoint **moderate**: 10 to 20% change in measurement endpoint **high**: >20% change in measurement endpoint	**local**: effect restricted to the LSA **regional**: effect extends beyond the LSA into the RSA **beyond regional**: effect extends beyond the RSA	**short-term**: <3 years **medium-term**: 3 to 30 years **long-term**: >30 years	**reversible** or **irreversible**	**low**: occurs once **medium**: occurs intermittently **high**: occurs continuously

4.3.5.4 Mitigation

Mitigations that will moderate the impact of habitat loss or alterations as a result of riparian clearing, removal of streams and wetlands, change in hydrology and changes to water quality include the following:

Design Features

- Staged clearing of the tailings area to minimize disturbance to watercourses.
- Maintain watercourse buffers within the tailings pond area as long as feasible to maintain on-site water quality and habitat function.
- Implementation of watercourse crossing guidelines and plans which minimize in-water work and disturbance of aquatic /riparian habitat and control sediment levels within specified levels to protect aquatic habitat and biota.
- Other mitigations related to water management in the tailings facility are provided in the hydrogeology, hydrology and water quality assessments (Volume E, Sections 3.7, 3.8 and 3.9).

Reclamation

- Revegetation of all disturbed riparian habitats at road and pipeline watercourse crossings (part of Environmental Management plans during construction).

4.3.5.5 Results

Riparian, Stream Channel and Wetlands Displacement

Tailings Disturbance Area

The footprint of the tailings area will result in the physical loss of stream and riparian habitat; much of this is agriculturally disturbed, however the locally rugged terrain retains some small headwater features and low forest or vegetated riparian stream habitat.

Streams within three sub-basins will be directly disturbed by channel or flow loss, or indirectly severely disturbed in immediate downstream reaches of the watershed by diversion of most of the baseline flow during construction. The extent of watercourse loss and displacement is summarized in Table 4.3-6.

An estimated total of 4.6 ha of stream habitat (instream wetted area) within 36 km of channel will be eliminated by the tailings facility. The greatest number of streams affected within the immediate disturbance area will be the 1st order streams. Many of the 1st order watercourses do not appear to support fish populations, but do contain un-described communities or species of aquatic macro-invertebrates and flora (algae or periphyton). They also provide an important influence on downstream aquatic habitat quality through flows and physical or chemical characteristics (i.e., water temperature, oxygen, sediment and nutrients).

The 2nd and 3rd order streams, which support a majority of the fish resource within the footprint of the disturbance area, comprise about half the area of habitat lost (estimated 2.4 ha wetted channel area). These slightly larger streams are generally located in disturbed habitats (hillside agriculture, deforestation and stream control for flooding of wetlands for the production of rice). The two sites within the tailings area were classified as highly modified or critical (IHIA Class D and E) based on habitat integrity assessments (Kleynhans 1996) of the aquatic and riparian habitats, however they still contained significant endemic and native aquatic communities.

Table 4.3-6 Predicted Aquatic Habitat Loss as a Result of the Displacement of Streams and Wetlands by Tailings Facility Construction[(a)]

Habitat Type	Number and Mean Width (m)[(b)]	Channel Length (m)	Est. Wetted Area (ha)
Streams 1st order	50 (0.50)	24,901.9	1.25
Streams 2nd order	13 (2.39)	4,547.4	1.09
Streams 3rd order	4 (2.70)	4,982.7	1.35
Streams 4th order	1 (5.31)	1,697.2	0.90

(a) Within tailings footprint and boundaries of three sub-basins of the Ambolona watershed.

(b) Mean width in 2nd, 3rd, 4th order streams calculated from survey site habitat observations (average of high and low flows); no on-site data available for 1st order streams, width estimated.

Service Corridors and Infrastructure

Ancillary facilities (i.e., the access road and the tailings pipeline from the process plant and the water discharge pipeline) can disturb riparian and aquatic habitat and fauna in study area watercourses by instream construction activities and by surface runoff (i.e., sediment from erosion). Along the proposed tailings service corridor three permanent watercourses will be crossed. A majority of the watercourses within the service corridor exhibit highly modified habitats, and will exhibit a low sensitivity to minor disturbance. Based on habitat characteristics and the IHIA model for site TMT001 (the lower Ambolona tributary, which will be crossed by the service corridor) the stream habitat condition was rated as Class E (extensive modification of riparian and instream ecosystems). A similar habitat condition and sensitivity to construction is expected for other watercourses along this corridor.

Construction effects from instream activity during crossings of these watercourses will be primarily a short-term disturbance of riparian and instream habitat. Watercourse crossing guidelines will be followed to prevent or mitigate harmful effects on aquatic habitat (addressed in Volume E, Section 7, Environmental Management Plans) and impacts are not anticipated from construction activities associated with the service corridor. However long-term, permanent local disturbance could occur depending on the type and size of road crossing (culvert, bridge) used for roads, and its effect on stream hydrology and channel morphology.

Change in Downstream Water Flow and Quality

Clearing of the tailings area, diversion of streams, and operation of the tailings facility will affect surface water quantity and quality (runoff and effluent tailings) in the streams draining the project area. These changes may alter riparian and instream aquatic habitat and affect the presence and abundance of critical habitat for aquatic biota in portions of the receiving watersheds. Five regionally endemic fish species were found in the sites downstream of the tailings facility. Severe habitat alterations could jeopardize habitat refugia that these species likely use to presently maintain their populations in the presence of exotic species, modify invertebrate populations, and also affect the quantity of available stream habitat for the non-indigenous fish species used by local artisanal fisheries.

Downstream Flow Changes

Development of the tailings facility will impact downstream flows from the existing area of the Ambolona basin; the amount of change in flow will differ between sub-basins and the stage of development or use of the basin for tailings deposit (Hydrology assessment, Volume E, Section 3.8).

During operations significant decreases in flow will occur in the mainstem tributary below the tailings impoundment since storm water will be collected in the tailings impoundment and managed with the tailings effluent and discharged to the ocean. Decreases in flow during average runoff conditions are expected to range from 34 to 66% (by year 27 of the project). These decreases will affect minimum flow balances for maintenance of fish, alter physical aquatic habitat parameters and result in changes to the aquatic ecosystem and ecosystem function. The downstream impacts on aquatic habitat from flow alterations in this range are considered high in magnitude.

Water Quality Changes

Water quality changes affecting aquatic habitat in the tailings area could be associated with runoff, seepage or spills from the tailings impoundment, instream work activities, erosion (sedimentation) during surface water runoff, spills or, groundwater affected by tailings materials. The water management plan for the tailings supernatant will maintain acceptable water quality for discharge to the sea; however seepage and overflow or spill potential could impact local downstream freshwater habitats.

Increased turbidity and sedimentation during construction are the primary water quality changes which may affect aquatic ecosystems along the pipelines and access road service corridors. The use of applicable Environmental Management guidelines during construction will minimize potential effects and impacts on water quality from this activity will be low.

4.3.5.6 Impact Analysis

Residual Impacts

Residual impacts of aquatic habitat loss as a result of the construction, operation and closure of the tailings facility are summarized in Table 4.3-7.

The status of aquatic habitat in the tailings area is moderately well understood, but the level of baseline information for some habitats (1^{st} order streams and wetlands) is low. The prediction confidence for impact ratings for habitats within the disturbance area is high, as there is very limited potential for mitigation. The prediction confidence for impact ratings for habitats downstream, is considered moderate and is dependent on the assessment for hydrology and water quality.

Closure and reclamation goals are designed to establish suitable vegetation cover to allow clean surface runoff to downstream basins.

Table 4.3-7 Potential Effects and Residual Impacts for Aquatic Habitat in the Tailings Facility

Project Period	Potential Effects	Mitigation	Residual Impacts
construction	direct displacement and loss of critical riparian and instream and aquatic habitats effects on downstream flow and water quality during construction effects on aquatic and riparian habitat during pipeline and road construction	local water management	high magnitude/long-term modification of local water bodies and watercourses within the tailing disturbance area low magnitude / short-term habitat disturbance during infrastructure construction low magnitude /long-term loss from footprint of some facilities (bridges, culverts)
operation	potential alteration of downstream watercourse habitats for aquatic biota as a result of water flow and water quality changes potential water quality effects on fish and aquatic biota	water management erosion and sediment control systems	high magnitude / long-term modification of downstream watercourses low magnitude / medium-term modification of downstream watercourses and wetlands
closure	changes in the landscape and development of vegetative cover to offer clean surface drainage downstream	water management; erosion control on-site reclamation	low magnitude / long-term modification of reclaimed topography and drainage system

An overall residual impact classification is presented in Table 4.3-8; the overall environmental consequence scores were based on the screening system described in Volume A, Section 7.

Table 4.3-8 Residual Impact Classification for Effects on Aquatic Habitat

Phase	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Effect: Elimination of Riparian, Instream and Wetlands Aquatic Habitats							
construction	negative	high	local	long-term	no	medium	high
operations	negative	high	local	long-term	no	medium	high
Effect: Downstream Watershed Flow and Water Quality Changes							
construction	negative	low	local	medium-term	no	medium	low
operations	negative	high	local	medium-term	no	medium	high
closure	negative	low	local	long-term	no	medium	low
Effect: Habitat Disturbance and Water Quality Changes from Infrastructure (Service Corridor)							
construction	negative	low	local	short-term	yes	low	negligible
operations	negative	low	local	long-term	yes	low	negligible
Effect: tailings facility reclamation[(a)]							
closure	positive	n/a	n/a	n/a	n/a	n/a	n/a

(a) Effect during closure assumed only if viable aquatic habitat can be restored.

n/a = Criteria not ranked for positive effects.

The area downstream from the tailings is largely disturbed, however it still maintains a good diversity of fish and aquatic resources. Given the predicted high residual impact to these aquatic habitats, the proponents propose to discuss strategies for improved management techniques with local stakeholders and Malagasy fisheries experts.

Monitoring

No monitoring is proposed specifically for construction or operational effects on aquatic habitat within the tailings disturbance area, as these units will be eliminated during development of the facility. However, water quality and water flow will be monitored in release waters and downstream, and during construction, as described in Volume E, Sections 3.8 and 3.10. Selected aquatic resources will also be monitored downstream of the tailings, to test impact predictions. Post-disturbance monitoring of stream flow and water quality will be implemented to ensure the effectiveness and integrity of reclaimed tailings area.

4.3.6 Key Question FA-2: What Effect Will the Project Have on the Abundance of Aquatic Biota and Survival of Endemic or Native Species?

4.3.6.1 Impact Pathways

The abundance and survival of fish and other aquatic biota can be affected by activities during tailings construction, operation and closure phases. Changes will result primarily from:

- community (habitat) modification;
- changes to fish and ecosystem health; and
- restoration activities.

Community (Habitat) Modification

Presence, abundance and survival of fish and aquatic biota is directly linked to habitat. Physical habitat assessments have been discussed in Key Question FA-1; the use of these ecosystems by fish species and/or macro-invertebrates will be expanded here.

Removal and drainage of existing watercourses and water bodies eliminates the capability of the local area to support fish and other aquatic biota, and may also result in the mortality of biota within the disturbance area. Change in flows and water quality can directly affect the life history function of fish downstream of the tailings facility. Disturbance of fish and invertebrate populations will also occur during watercourse crossings associated with the service corridor. Loss and disturbance of the aquatic communities will occur during the construction, operation and closure of the tailings facility.

Fish and Ecosystem Health

Fish and ecosystem health effects result when the physical or chemical characteristics of water vary outside the normal tolerance range of fish or other aquatic biota. Change in health can result from construction and/or operation of the tailings facilities and associated infrastructure. Ecosystem health can be affected by contaminants (from spills, effluent discharges and air emissions), changes in water quality (entrained sediments, introduced contaminants) and quantity (flows), with lethal, sub-lethal or chronic effects on fish and aquatic biota.

Restoration Programs

Upon closure the tailings facility will implement surface revegetation to allow for clean runoff into downstream basins.

4.3.6.2 Assessment Methods

Habitat loss data generated for watercourses (Key Question FA-1) and habitat integrity information developed during the baseline site surveys was related to the species taxonomy and community composition data (fish and macro invertebrates) described by qualitative and quantitative population sampling during the baseline survey within the LSA. The conservation status of endemic and native fish species was reviewed from recent published checklists and the IUCN Red List (2004). Fish and ecosystem health was judged by interpretation of predicted water quality and quantity data (Volume E, Sections 3.7, 3.8 and 3.10); baseline contaminant data on aquatic biota was collected from fish and invertebrate samples (discussed in human and ecological health, Volume E; Section 5.4).

Tailings closure plans and literature were used to evaluate endemic fish species recovery options.

4.3.6.3 Mitigation

Mitigations that will minimize the loss of fish and invertebrate communities from activities associated with the tailings construction and operation include:

Design Features

- Mitigations and procedures for aquatic habitat (as presented in Section 4.3.5.4) will provide direct or indirect protection to fish species, communities and other aquatic biota.
- Water management plans and facilities will be designed to minimize potential releases or spills of tailings water to the Ambolona watershed; tailings supernatant along with collected storm water will be discharged to the ocean via pipeline to avoid disposal to the smaller freshwater environments in the LSA.

Construction, Operation and Closure

- Implementation of a fish salvage program to allow for the release of salvaged endemic fish into similar or suitable habitats where available.

- Work closely with local Malagasy fisheries experts to discuss strategies for improved management techniques.

4.3.6.4 Results

Habitat Modification

The fish fauna within the tailings LSA contains five endemic fish species (*Ambassis fontoynonti, Bedotia madagagascariensis, Hypsleotris tohizanae, Ophiocara macrolepidota* and *Sauvagella madagascariensis*). Endemics were collected from all LSA sites.

The tailings LSA contains a low number of endemic species relative to the 27 described endemic species reported for this ecoregion of Madagascar (Sparks and Stiassny 2005); however the range of many endemics has contracted and localized due to habitat degradation and introduced competitors and predators (Ravelomanana 2004). All species encountered in the LSA have been previously reported within this eastern lowlands region (CAMP 2001 and Volume B, Section 4.3, Figure 4.3-1).

Tailings Disturbance Area

The tailings facility will eliminate the upper drainage habitats supporting endemic and native populations; however there was no clear distributional use of these areas relative to the lower drainage sites (downstream of the tailings pond), and their significance to the life history (i.e., critical habitat features, etc.) of the species is unknown. The valley hillsides in these areas contain forested headwaters which maintain good water quality, in spite of the local agricultural practices, and some of the accessible streams may supply refugia for these populations.

The tailings facility will also create a movement barrier to the upstream migration of some fish, possibly to important or critical habitats. Insufficient information is available on the biology of all endemic and native species in the study area to confirm this. However, within the fish community at the lower sites, significant temporal difference in species association and abundances was observed between high flows and low flows, suggesting some seasonal movement or migration within the watercourses in the study area. Also, the life history of the *Anguillidae* (eels) involves a freshwater migration from and to the sea; therefore access to the preferred habitats used by these species in the upper drainages of the tailing pond will be blocked.

Mitigations (i.e., fish salvage) will be implemented in an attempt to save fish where practical; however unquantifiable mortalities will occur during this program, and the potential success of any potential species culture or recovery program is unproven.

Impacts on non-indigenous (exotic) fish communities within the tailings disturbance boundary will be equally as severe; however population level impacts to these species outside the boundary of the tailings disturbance are likely to be insignificant because of their widespread distribution and habitat adaptability.

Downstream Drainages

The downstream sites, located in the lower portion of the three drainage basins, exhibited a slightly higher overall diversity of fish and invertebrate biota. Endemics were again present at all sites, with three additional endemic species (*Ambassis fontoynonti*, *Hypsleotris tohizanae* and *Sauvagella madagascariensis*) found in these lower reach habitats. *Ambassis* is IUCN listed (DD) but the others are not listed and not generally considered threatened. However, there is a lack of knowledge of life history and habitat use by these endemics, and in the face of continued stream degradation and invasion of exotic competitors, the rate of decline of populations will continue and the species will likely become endangered. During the low flow period, *B. madagascariensis* was the most abundant of all species at three of the four sample sites.

The tailings facility will collect storm water that falls within the facility. This water combines with the tailings supernatant and the combined effluent will be released to the ocean. This will result in significant downstream flow reductions in the Ambolona tributaries. Changes to the species structure, abundance and use of downstream aquatic communities, and potential interference with movements or migrations (possibly spawning or feeding related), will occur with the greatest impact in reaches of the Ambolona nearest to the tailings facility. Downstream impacts related to flow loss are considered high in magnitude, and could affect the long-term ability of these endemics to maintain their populations downstream of the tailings area.

Service Corridor (Road, Tailings Pipeline and Discharge Water Pipeline)

Combined populations of endemic species and exotics were encountered at the tailings service corridor crossing. Disturbance to resident fish populations in these locations may occur as a result of habitat alterations and water quality changes (sedimentation) during construction at watercourse crossings. However these effects will be mitigated, temporary and low impact.

Long-term impacts on fish communities may occur if permanent structures such as bridges or culverts are installed at the crossing, but is expected to be low in magnitude. The potential for pipeline breaks during operations is considered a low risk due to design and maintenance practices, therefore impacts on water quality and biota are considered to be low.

Fish and Ecosystem Health

Changes to fish and ecosystem health could occur primarily on a local level as a result of the effect of increased sediment entrainment during construction. Routing of tailings effluent to the ocean and mitigation to intercept groundwater seepages will largely eliminate downstream water quality effects on aquatic biota. Accidents and spills into water bodies downstream of the tailings facility including emergency releases from the tailings area (in the event of storms greater than the 1:50 year design for the tailings berms) are still a concern.

Restoration

Upon closure vegetation cover will be re-established to allow clean runoff into the downstream valleys to once again replenish the flows.

4.3.6.5 Impact Analysis

Residual Impacts

Residual impacts of changes to the abundance and structure of aquatic communities and the survival of endemic species as a result of the tailings facility construction, operation and closure are summarized in Table 4.3-9.

The status of fish species in the tailings area is moderately well understood, but the level of information on basic biology and life history for most endemic fish species and other endemic aquatic biota is very limited. The prediction confidence for impact ratings for biota within the disturbance boundary is high, as there is very limited potential for preservation. The prediction confidence for impact ratings for fish and aquatic communities downstream, is low because of the limited understanding of life histories and the ecological functions of the downstream systems.

Table 4.3-9 Potential Effects and Residual Impacts for Aquatic Species Abundance and Survival in the Tailings Facility Area

Project Period	Potential Effects	Mitigation	Residual Impacts
construction	direct mortality and eradication of important endemic aquatic species effects on downstream flow and water quality during construction effects on aquatic and riparian habitat during service corridor construction	local water management erosion control system design fish salvage program	high magnitude/long term modification fish and aquatic fauna within the disturbance area low magnitude / short term habitat disturbance during infrastructure construction
operation	continued loss of aquatic biota associated with drainages on the tailings area change to downstream aquatic biota as a result of water flow and water quality changes	water management plan erosion and sediment control system design	high magnitude / long-term modification within the local disturbance area low magnitude / medium-term effect on downstream communities due to water flow and quality change
closure	changes in the landscape and development of revegetative surface to support clean runoff to downstream basins	ensure control systems are functioning to maintain flow and water quality to support aquatic habitat	low magnitude / long-term endemic species recovery

An overall residual impact classification is presented in Table 4.3-10; environmental consequence scores used the screening system described in Volume A, Section 7.

Table 4.3-10 Residual Impact Classification for Effects on Aquatic Species Abundance and Survival in the Tailings Area

Phase	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Effect: Community (Habitat) Modification							
construction	negative	high	local	long-term	no	medium	high
operations downstream	negative	low	local	long-term	no	medium	high
Effect: Change to Fish Health							
construction	negative	low	local	short-term	yes	low	negligible
operations	negative	low	local	long-term	yes	low	negligible
Effect: Restoration and Species Re-introduction							
operations[(a)]	positive	n/a	n/a	n/a	n/a	n/a	n/a
closure	positive	n/a	n/a	n/a	n/a	n/a	n/a

(a) Effect during operations assumed to be off-site.

n/a = Criteria not ranked for positive effects.

As discussed for habitat impacts, the high residual impacts at the species level, emphasise the need to discuss strategies for improved fish management techniques with local stakeholders and Malagasy fisheries experts.

Monitoring

- Monitoring of flow and water quality in key streams to ensure protection systems are functioning.
- Selected monitoring of aquatic resources downstream of the tailings to confirm impact predictions.

4.3.7 Key Question FA-3: What Effect Will the Project Have on Artisanal Fisheries?

4.3.7.1 Impact Pathways

The local artisanal fisheries and harvest of freshwater aquatic biota (consisting primarily of fish, shrimp and snails) can be affected by activities in the tailings area during construction, operation and closure phases. Changes may result from:

- availability of fish or other biota;
- fish health; and
- species changes.

Availability

Tailings operation could interfere with or eliminate fish populations being currently harvested in the LSA. This has been addressed in the previous sections.

Health and Condition

Changes to fish health and condition could occur due to construction and operational activities, including tailings effects on drainages and infrastructure.

Species Changes

Species may change as a result of habitat degradation during operations. Species changes may also occur during closure and reclamation.

4.3.7.2 Assessment Methods

Tailings development plan information was reviewed related to the aquatic environment and local villages or residences.

Fish or invertebrate species harvest by artisanal fisheries was determined from baseline observations and communications in the LSA, projected by professional judgment from the species composition observed, or from published reports.

Fish health was judged by interpretation of predicted water quality and quantity data; baselines for metal contaminant data for fish and gastropods collected in the LSA was assessed (reported in Volume E, Section 5.4, Human and Ecological Health).

4.3.7.3 Mitigation

Construction, Operation and Closure

- Provide salvaged fish for local use or sale.
- Work closely with Malagasy fisheries experts on developing fishery management techniques, including development of local pond fisheries.

4.3.7.4 Results

Changes in fish or biota availability will occur as a consequence of the loss of watercourses in the tailings area, and impacts to downstream habitats. Quantification is difficult; however, based on available habitat, species abundance and observed use, the upstream areas (tailings footprint) are less important than the larger water bodies downstream; however the impacts for both areas are considered negative and potentially high in local consequence.

Changes to fish health and condition could occur on a local level through increased sediment entrainment during instream construction activities, a low risk of pipeline breaks or spills into water bodies, tailings effluent releases, deposition of air emissions into local water bodies, and seepage or infiltration from the tailings area affecting local surface or groundwater downstream of the tailings area. Mitigations and environmental management plans related to sediment input, air emissions, surface water flow and water will limit these changes to accepted standards and will also be monitored. Therefore the effects on fish health and condition are considered low after mitigation, with a low environmental consequence.

Species change may occur due to habitat degradation caused by project-related activities. The impacts on local fish use and harvest are difficult to assess, but effects may be neutral as many of the fish currently harvested are exotics (i.e., *Tilapii sp*.) which are tolerant of habitat alterations.

4.3.7.5 Impact Analysis

Residual Impacts

Residual impacts of changes to the local use and harvest of fish and aquatic biota as a result of the tailings facility construction, operation and closure are summarized in Table 4.3-11.

The extent and use of aquatic resources within the tailings disturbance area is based on observations during field programs. The level of quantifiable information on specific use and harvest of aquatic resources in the tailings and downstream area of the LSA is low, but it is known that specific fish families (*Anguillidae*, eel and *Bedotiidae*, rainbow fishes) are fished for in this area. Despite this limitation, the nature of the impacts from construction are well understood and therefore the prediction confidence for impact ratings is considered medium.

Closure goals will re-establish down stream flows, thus offering higher water levels for increase in aquatic abundance.

Table 4.3-11 Potential Effects and Residual Impacts on Artisanal Fisheries in the Tailings Area

Project Period	Potential Effects	Mitigation	Residual Impacts
construction	eradication of important fish species during drainage effects on aquatic species during service corridor construction	fish salvage; potential availability for local use or sale; and endemic relocation	moderate magnitude/long-term loss within the mine disturbance area low magnitude / short-term loss during infrastructure construction
operation	loss of aquatic biota associated with drainages in the tailings area potential change in availability of downstream aquatic biota as a result of flow changes change to quality of fish as a result of contamination	work closely with local Malagasy fisheries experts to develop suitable management plans tailings water management plan	moderate magnitude / long-term moderate magnitude / medium-term change in the local area low to negligible effects on fish harvest from potential contamination[(a)]
closure	establish tailings vegetative cover to ensure clean runoff to downstream basins.	increase and control downstream flows and quality	low magnitude / long-term harvest of aquatic biota

(a) See Volume E, Section 5.4.

An overall residual impact classification is presented in Table 4.3-12; the overall environmental consequence scores were based on the screening system described in Volume A, Section 7.

Table 4.3-12 Residual Impact Classification for Effects on Artisanal Fisheries

Phase	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Effect: Change in Availability							
construction	negative	moderate	local	long-term	no	long	moderate
operations	negative	moderate	local	medium-term	yes	medium	low
Effect: Changes in Fish Health							
construction	negative	low	local	medium-term	no	short	low
operations	negative	low	regional	medium-term	no	medium	moderate
closure	positive	low	local	long-term	no	medium	low
Effect: Change in Species Composition							
operations	neutral	low	local	long-term	no	low	low
closure	positive	n/a	n/a	n/a	n/a	n/a	n/a

n/a = Criteria not ranked for positive effects.

Monitoring

Closure monitoring of flow and water quality to ensure protection of downstream aquatic environments.

4.3.8 Conclusions

High environmental consequences for local aquatic habitat and endemic fish species abundance and survival are predicted due to residual impacts from construction and operation of the tailings facility. For this reason, monitoring, coupled with support for local fishery management initiatives, will be pursued.

Downstream impacts on aquatic habitat and species are expected to be high in the LSA because of the consequences of flow reduction. The effects on local use and harvest of fish are expected to be of moderate to low consequence.

4.4 MARINE ECOLOGY

The Environmental Assessment for marine ecology is provided together with the assessment for oceanography in Section 3.9 of this Volume.

4.5 NATURAL HABITATS AND BIODIVERSITY

The effects of the Ambatovy Project (the project) on natural habitats and biodiversity in the area of the tailings facility are described in Volume D, Section 4.4. Effects of the tailings facility are evaluated together with the effects of the process plant due to the close proximity of these two developments.

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4.6 PROTECTED AREAS

Effects on protected areas relating to the tailings facility are addressed in combination with all effects occurring due to the Ambatovy Project in the Toamasina region. These effects are presented in the process plant volume (Volume D, Section 4.5).

5.1 SOCIOECONOMICS

Socioeconomic effects of the tailings facility in combination with other components of the Ambatovy Project in and around Toamasina are addressed in Volume D, Section 5.1.

5.2 CULTURAL PROPERTY

5.2.1 Introduction

This section presents the Environmental Assessment for the effects of the tailings site on cultural resources, as per the Ambatovy Project (the project) Terms of Reference.

5.2.2 Study Area

The Local Study Area (LSA) used for the cultural property impact assessment comprises the footprint area of the tailings site. Some cultural resources have been identified outside of the current footprint area, and are included in this study for the sake of completeness. These sites will not have any bearing on recommendations made in the impact assessment portion of this report.

5.2.3 Baseline Summary

The following provides a summary of the results of cultural resources studies that have been conducted within the project tailings footprint. A complete description of the baseline methods, analysis and results is located in Volume K, Appendix 2.1.

5.2.3.1 Methodology

Pre-field work consisted of analyzing the results of previous historical studies completed in the general region. Regional toponyms were also studied, as place-names can assist in reconstructing the particular history of an area.

Fieldwork was completed at Toamasina between June and July of 2005. Systematic pedestrian transects were used to visually inspect the study area. Local expertise was also consulted by questioning villagers about the locations of any known archaeological or cultural sites in the area. A global positioning system (GPS) was used to plot the coordinates of sites found during the survey.

5.2.3.2 Site Diversity

Table 5.2-1 below illustrates the different kinds of cultural sites that are known to exist in the general region.

Table 5.2-1 Potential Types of Cultural Sites in the Cultural Resources Study Area

Site Category	Sub-Categories	Cultural Relevance
tombs	Fasana	considered ancestral residences, their displacement requires careful attention to proper ritual
	Tranomanara	
	Feraomby	
cemeteries	--	as above
ceremonial sites	Jiro	family prayer altar
	Fisokona	communal prayer altar
nefarious places	Tany Mahery	bad luck area
sacred waterfalls	Riana	symbolize purity; place for offerings
other cultural / archaeological sites	Vatolahy	large raised stone commemorating an important person or event of the past
	Tsangambato	small raised stones symbolizing a tomb
	Tanana Taloha	ancient abandoned villages

With the exception of the ancient abandoned villages, which are purely archaeological, the rest of these sites listed in Table 5.2-1 may be considered cultural because they continue to play a role in the current culture of the area.

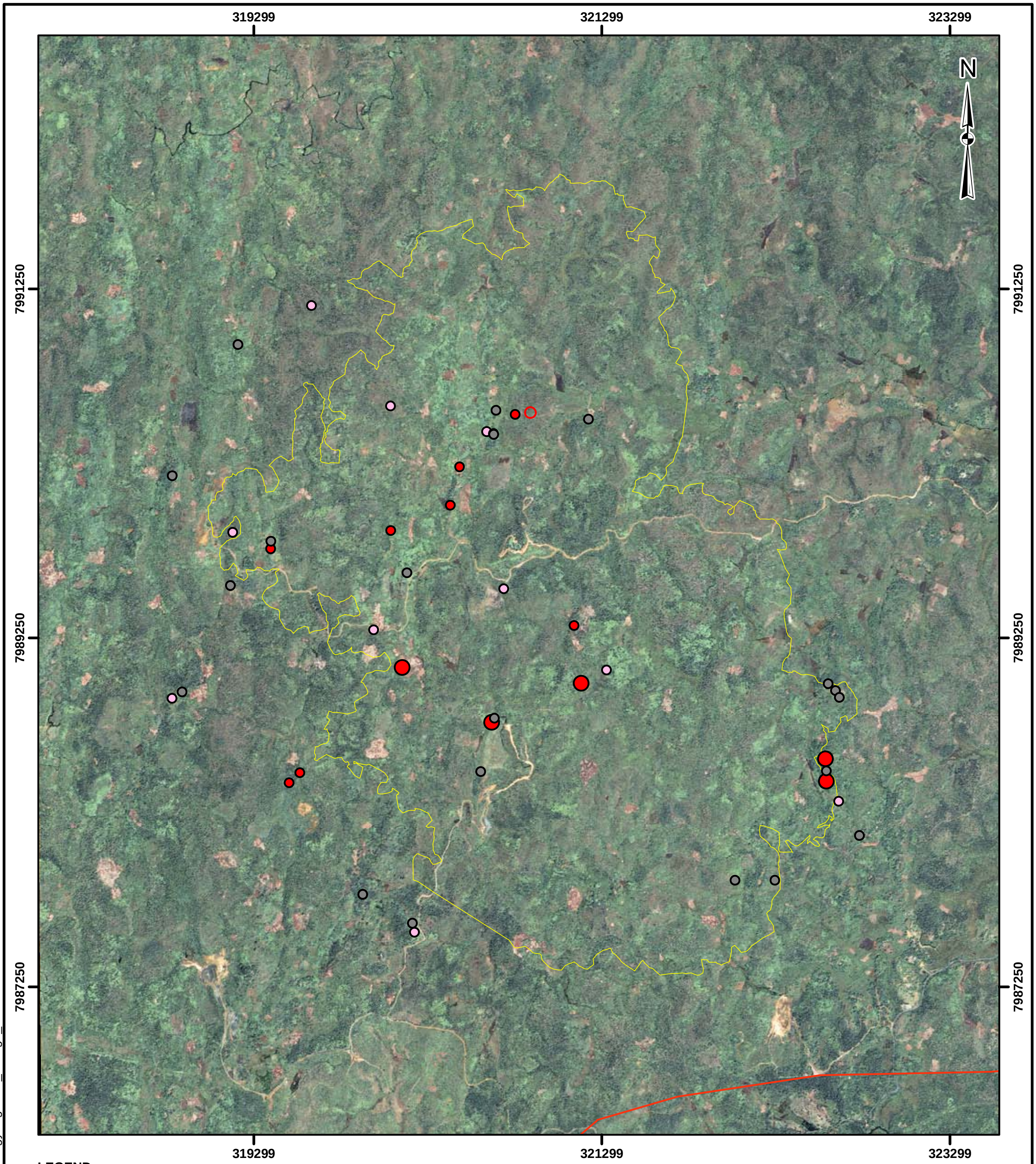
5.2.3.3 Results

During the assessment of the tailings area, seven tomb sites, 12 ceremonial sites, 10 archaeological sites, and one symbolic tomb site were located (see Figure 5.2-1). Seven ceremonial sites, three tomb sites, and two archaeological sites were also found near (<1 km) the tailings area boundary.

5.2.4 Issue Scoping

The main potential issues relating to cultural resources are:

- destruction of cultural sites during tailings construction (primary impacts); and
- disturbance of nearby cultural sites during and after tailings operation (secondary and tertiary impacts).



LEGEND

- ARCHAEOLOGICAL SITE
- CEREMONIAL SITE
- SYMBOLIC TOMB
- TOMB SITE
- SLURRY PIPELINE
- SITES REQUIRING PRE-IMPACT EXCAVATION AND DATA LOGGING
- TAILINGS FACILITY BOUNDARY

500 0 500 1,000

SCALE 1:30,000 METRES

REFERENCE

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

I:\2003\03-1322\03-1322-172\mxd\Archaeology\Fig5.2-1_tailings_Oct25.mxd

PROJECT

AMBATOVY PROJECT

TITLE

VIEW OF TAILINGS FACILITY AND LOCATIONS OF ARCHAEOLOGICAL AND CULTURAL SITES

Golder Associates
Calgary, Alberta

PROJECT No. 03-1322-172			SCALE AS SHOWN	REV. 0
DESIGN	LB	13 Sep. 2005	**FIGURE: 5.2-1**	
GIS	LL	25 Oct. 2005		
CHECK	GJ	09 Feb. 2006		
REVIEW	DM	09 Feb. 2006		

Cultural resources are non-renewable resources that may be located at or near ground level, or may be buried. Primary impacts to these comprise disturbances created by the construction of the development project, where the landscape and its contents are disturbed.

Secondary impacts are indirect impacts that occur after construction and reclamation is complete. Erosion of sloping terrain due to alterations in the vegetation, for example, may affect sites. Secondary impacts are of particular concern in situations where cultural resources lie adjacent to development zones.

Tertiary impacts are the results of project-induced changes in demography and land-use patterns. Increased rates of intentional and unintentional impacts can be expected as a result of increased visitation to the region if the project is large enough to affect regional population bases. For this project, tertiary impacts may be possible from non-local workers unfamiliar with local customs.

The key questions for cultural resources are:

Key Question AR-1 What Effect Will the Project Have on Archaeological Sites?

Key Question SE-8 Will the Project Lead to Cultural or Social Conflicts Between Local Residents and Outsiders?

Key Question SE-10 What Effect Will Resettlement From the Project Within the Area of Direct Impact Have on Inhabitants?

5.2.5 Impact Assessment

5.2.5.1 Assessment Methods

Assessment methods consisted of identifying which cultural resources discovered during the fieldwork phase would be directly impacted by construction activities.

Secondary impacts relating to hydrologic or soil erosion effects outside of the project footprint were evaluated based on impacts predicted in the hydrology and soils EA sections (Volume E, Sections 3.8 and 3.3).

Cultural resources may suffer tertiary impacts (through increased visitation to the area by non-local residents following construction of the project). These impacts are difficult to predict, but can be mitigated. They are only broadly alluded to in this assessment.

5.2.5.2 Assessment Criteria

The assessment criteria used for cultural resources are presented in Table 5.2-2.

Table 5.2-2 Impact Description Criteria for Cultural Resources

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency
neutral: no effect on cultural resources **negative:** cultural resources are destroyed	**negligible**: no measurable effect on cultural resources **moderate:** tertiary impact on cultural resources **high:** primary impact on cultural resources	**local:** effect restricted to the tailings facility **regional:** effect extends beyond the tailings facility (secondary impacts)	**medium term:** 3 to 30 years **long term:** >30 years to permanent	reversible or irreversible	**low:** occurs once **medium:** occurs intermittently **high:** occurs continuously

5.2.5.3 Impact Analysis

Residual Impacts

The residual impacts during each project period are summarized in Table 5.2-3.

Table 5.2-3 Potential Effects and Residual Impacts for Cultural Resources

Project Period	Potential Effects	Mitigation	Residual Impacts
construction	perturbation of the landscape and associated cultural resources sites	relocation of tombs, symbolic tombs, and ceremonial sites excavation of five archaeological sites	neutral magnitude, but permanent and irreversible effects
operations	increased presence of non-local workers in region	cultural sensitivity training	potential moderate magnitude, medium-term and reversible effects on cultural resources adjacent to tailings facility
	off-site hydrologic and erosion impacts	staged development, erosion control, reclamation	none
closure	none	none	none

5.2.5.4 Mitigation

Of the ten archaeological sites found in the tailings footprint, five were judged to be old enough as to represent significant historical resources. For these five sites, which cannot be relocated, further work consisting of preliminary archaeological excavations to determine the exact nature of the sites, is required. Depending on the nature of the data recovered, additional excavations may be warranted.

The tombs, symbolic tomb, and ceremonial sites situated inside the proposed tailings impact zone will not impede construction provided they are relocated. According to accepted cultural practice, these may be moved without losing any of their significance or meaning. For this to occur, however, proper protocol involving correct rites and rituals must be observed. Discussions and negotiations with resident groups will be necessary in this regard. The process involved in re-locating tombs is outlined in Table 5.2-4.

The resettlement that will be required also implies a requirement to relocate tombs or other cultural sites associated with the households that have to be resettled, irrespective of their proximity to the actual construction impact zones.

Secondary impacts will include a reduction in downstream flow levels that may cause lands to be abandoned. The proponent will work with local residents to ensure water levels are adequate for continued agricultural activity, as described in the land use section (Volume E, Section 3.5), avoiding impacts to the use of cultural sites in downstream watersheds.

Tertiary impacts will be mitigated through cultural sensitivity training and by ensuring that non-local workers avoid visiting cultural resource sites adjacent to the direct impact zone of the development.

Table 5.2-4 General Procedure for Relocating Tombs

Steps	Procedures	Comments
1	identification of owners / descendants	this must be formally verified
2	initial discussion of options with owners	this first meeting is only to discuss options, not determine a final solution
3	later re-visit to enquire about owners' ideas and conditions	the choice of when and where the relocation should take place is left to the tomb owners
4	another re-visit to discuss: 1) materials and financial aspects of the owners' stated conditions 2) details of the ceremony	
5	launch the construction of new tombs, and probably new coffins	this requires a small ritual to be performed
6	gathering of required materials: burial linens, alcohol, zebu cattle, etc.	money may also be given to the locals in order for them to partially do this on their own
7	on the appointed day, the ritual will be conducted by an important village person	it would be ideal to conduct this entire process of exhumation and inhumation in one day

5.2.5.5 Conclusions

Following mitigation, the tailings facility will have a neutral effect on cultural resources during the construction phase. Although archaeological sites will be destroyed by mitigative excavations, the information obtained from these will offset their destruction (Prof. Jean-Aimé Rakotoarisoa pers. comm.; Volume K, Appendix 2.1). Because the tombs, symbolic tomb, and ceremonial sites located within the tailings project area may be displaced without altering their inherent cultural meaning, a neutral effect is also envisioned.

No secondary effects due to off-site hydrologic or erosion impacts are predicted.

A potential moderate, medium-term effect on cultural resources adjacent to the tailings may occur during the operations phase, depending on whether the non-local residents working in this area will come into contact with these.

No effects are envisioned for the tailings closure phase.

5.3 LAND USE

5.3.1 Introduction

This section presents the Environmental Assessment for the effects of the tailings facility on land use. As per the Ambatovy Project (the project) terms of reference, land use has been mapped in the tailings facility local study area (LSA) and changes in land use areas predicted in comparison to baseline levels. The implications of changes in land use for people are discussed in the context of socioeconomic effects in Volume E, Section 5.1.

5.3.2 Study Area

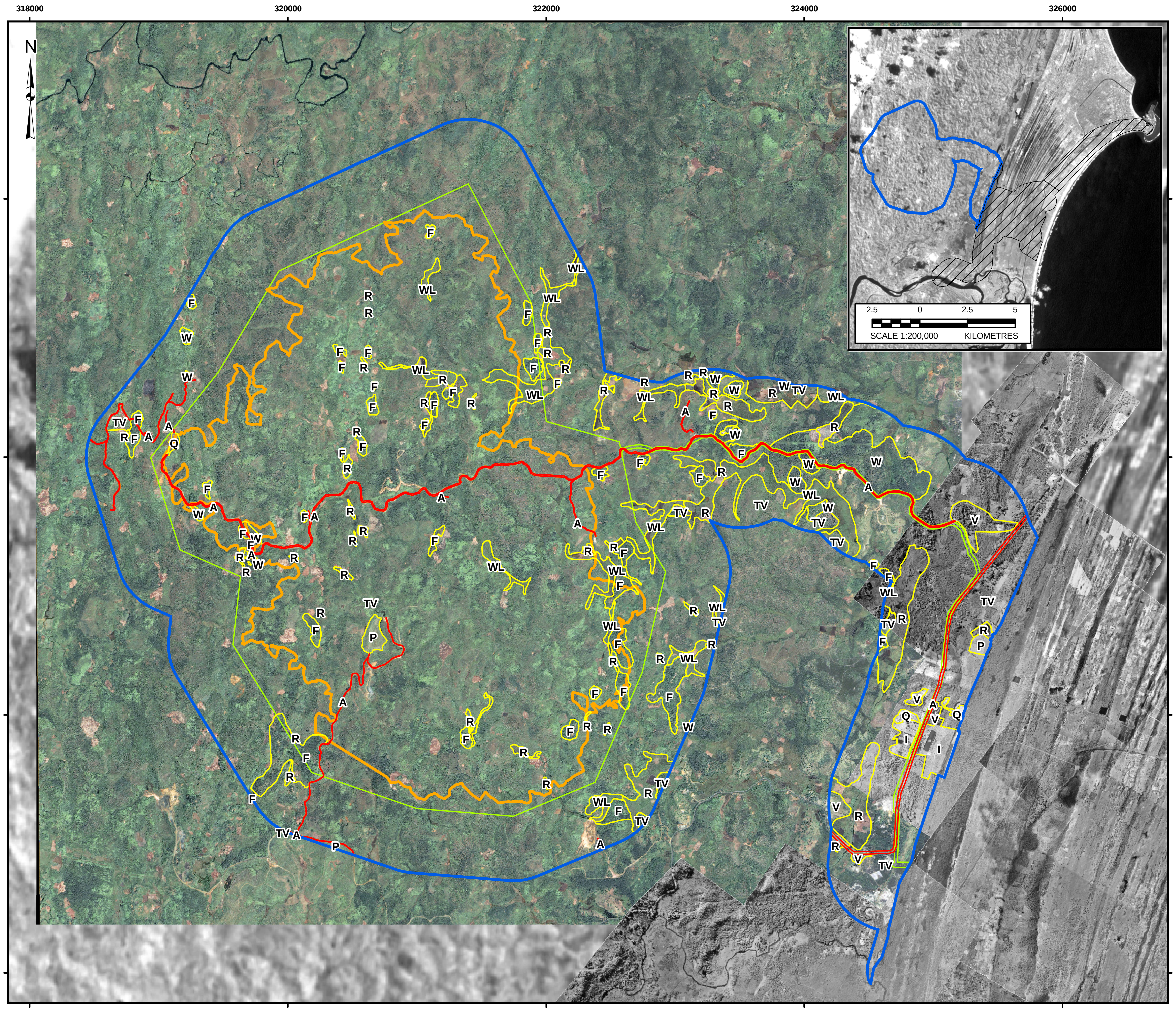
The tailings facility LSA is one-third of the Toamasina terrestrial LSA shown in Volume A, Section 7.2, Figure 7.2-3. This area includes the tailings facility property, the access corridor from the main highway to the tailings facility, and a 500 m buffer around both of these areas. The specific boundaries of the tailings facility LSA are presented in Figure 5.3-1.

5.3.3 Baseline Summary

Most of the tailings facility LSA is usable for tavy agriculture, but is not occupied by any specific land use (Volume K, Appendix 3.1, Section 3.5.1). Portions of the wide valley floors within, and downstream of the LSA have been developed into rice paddies. Homes and villages are located both in and downstream of the tailings facility, primarily within a short distance of the access route (ridge road) into the area.

In addition to eucalyptus woodlots, forest plots in the LSA include mango, litchis, coconut, banana, jack fruit, bread fruit, orange and clove trees. The ravenala trees that grow throughout the region are also of value for house construction.

A power line right-of-way (RoW) also crosses the tailings facility area, and a disused rock quarry is located at the west end of the ridge road traversing the area.



LEGEND

VEGETATION AND LAND USE CLASSIFICATION

- A ACCESS CORRIDOR
- VEGETATION/LAND USE TYPE
- F AGROFOREST AND SECONDARY FOREST VEGETATION
- I INDUSTRIAL
- P PLANTATION
- Q QUARRY
- R RICE PADDIES
- TV TAVY MATRIX
- V VILLAGE
- W WOODLOT
- WL WETLAND
- TAILINGS FACILITY SUB-LOCAL STUDY AREA
- TAILINGS FACILITY BOUNDARY
- CORRIDOR DISTURBANCE

REFERENCE

Landsat 7 Mosaic Image; Captured April/Sept. 2001
Aerial photograph Mosiac Images; Captured 2004
Datum: WGS 84 Projection: UTM Zone 39S

0.5 0 0.5 1
SCALE 1:30,000 KILOMETRES

PROJECT

AMBATOVY PROJECT

TITLE

LAND USE IMPACT AREAS WITHIN THE TAILINGS FACILITY SUB-LOCAL STUDY AREA

Golder Associates
Calgary, Alberta

PROJECT No. 03-1322-172.8000			SCALE AS SHOWN	REV. 0
DESIGN	DN	29 Jun. 2005		
GIS	TN	28 Oct. 2005		
CHECK	GJ	09 Feb. 2006	FIGURE: 5.3-1	
REVIEW	DM	09 Feb. 2006		

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5.3.4 Issue Scoping

Key issues raised by the public relating to land use during public consultations include:

- elimination of good agricultural lands;
- compensation for both landowners and land users without title;
- toxicity of the content of the tailings pond to people and livestock;
- downstream water quality and sedimentation effects, affecting water use and agriculture;
- changes to hydrology (water volumes, especially in rice growing areas); and
- the question whether reclaimed lands will be usable in the future.

Relocation planning is an important issue in relation to land use which is addressed in a separate document from the EA.

5.3.5 Assessment Methods

Land use changes are considered through a spatial analysis of the kinds of land use areas that will be altered by the project. Water volume changes are considered through an analysis of availability of water compared with water needs for agriculture, as described below. The effects of land use impacts are social in nature and are addressed within the impact rating system in the socioeconomics section (Volume E, Section 5.1).

The water needs were calculated for areas (both affected and non affected) downstream from tailings facility, based on the known areas of rice paddies in the LSA and downstream watersheds. The analysis assumed rice to be the main crop requiring water, and used rice areas to perform the calculations of water requirements, but an additional percentage of requirement was added on top of the rice needs to account for other kinds of agriculture.

The calculation of water needs was performed with the software CROPWAT developed by the Food and Agriculture Organization of the United Nations (FAO). It takes into account rainfall, rice evapotranspiration and soil percolation losses. It does not take into account water flow from upstream. Evaporation was calculated based on Penman-Monteith method.

CROPWATER software gives theoretical water needs for each decade (three decades / month), per hectare, based on details of rice transplantation. A coefficient of efficiency of the water network was then applied by Centre National d'Etudes et D'Applications du Génie Rural (CNEAGR) based on their experience in Madagascar (about 40% losses within irrigation channels).

The calculation was made for the dates of rice transplantation provided in Table 5.3-1.

Table 5.3-1 Rice Seasons by Planting Date

First Season	
5 December	Result 1
5 January	Result 2
5 February	Result 3
Water needs for the 1st season	S1 = Average (R1, R2, R3)
Second Season	
5 July	Result 4
5 August	Result 5
5 September	Result 6
Water needs for the 2nd season	S2 = Average (R4, R5, R6)
Water needs for the entire year	**S1 + S2**

These results per decade and per hectare were then multiplied by the rice surfaces in each area downstream from the tailings. A percentage of the resulting water volume requirement was added on to account for other agricultural needs.

5.3.6 Impact Assessment

A linkage diagram for land use is presented in Volume H, Section 9. Potential impact pathways between the tailings facility and changes in land use exist for:

- alteration of soils, terrain and vegetation;
- changes in agriculture in downstream areas due to hydrologic effects;
- changes in fish habitats and abundance; and
- changes in wildlife populations and/or distribution.

Alteration of Soils, Terrain and Vegetation

The impacts of the project on areas with a variety of potential land uses are presented in Table 5.3-2. Impact areas are mapped in Figure 5.3-1. Effectively, all lands within the property line of the tailings facility will become unavailable for land use during the project; the lands covered by tailings are conservatively assumed to be unavailable for agriculture on a permanent basis, although other land uses will likely be possible.

Table 5.3-2 Land Use Impact Areas for the Tailings Facility Local Study Area

Type of Area	Area Within LSA (Baseline) (ha)	Area Impacted (Operations) (ha)	Area Impacted (long-term) (ha)	Proportion of Area in LSA Impacted (long-term) (%)
degraded residual coastal woodland	0	0	0	0
azonal/transitional forest and scrub	0	0	0	0
primary zonal forest and marsh edge	0	0	0	0
degraded primary zonal forest	0	0	0	0
agroforest/secondary forest	66	27	19	29
plantation	7	3	3	43
woodlot	44	4	4	9
beach ridge complex	0	0	0	0
coastal shrubland/grassland complex	0	0	0	0
rice paddies	82	10	9	11
shrubland/herbaceous/pasture	0	0	0	0
tavy matrix	2,219	1,060	935	42
village/urban	14	0	0	0
wetlands	61	14	11	18
access corridor (road/rail)	18	11	11	61
industry (buildings or exploration areas)	14	0	0	0
canal	0	0	0	0
quarry	3	1	1	33
river/water	0	0	0	0
seasonal pond	0	0	0	0
total	**2,528**	**1,130**	**993**	**39**

Construction and operations of the tailings facility will occur in three phases; impacts on downstream water basins may not occur until many years into the project, but impacts described in Table 5.3-2 account for all of the effects of the project, including impacts to all lands within the property line around the tailings facility and along the footprint of the enlarged access corridor.

The most valuable land use areas within the tailings facility LSA at present are agroforestry areas, lowland rice paddies, eucalyptus woodlots/plantations, and villages. Within the LSA, 41% (27 ha) of agroforestry areas will be impacted during the operations phase and 29% (19 ha) of agroforestry areas will be permanently removed by the project. Twelve percent (10 ha) of rice paddies will be impacted during the operations phase and eleven percent (9 ha) of rice paddies will be impacted permanently by the project. Thirteen percent (7 ha) of woodlots/plantations will be affected by the project, both in the operations phase and permanently. No village areas will be affected by the tailings facility.

Land owners and land users will be compensated though re-settlement to properties of equivalent capability for agriculture; however, the process of relocation may have other effects. These subjects are addressed in the socioeconomic section (Volume E, Section 5.1).

Changes in Agriculture due to Hydrologic Effects

Changes in hydrology (surface water flow volumes) due to the project are discussed in Volume E, Section 3.8. The project has the potential to result in declines in water flow in specific watersheds, which may affect rice paddies and other agricultural activities in these watersheds. Between 0% and 67% of the flow into each sub-watershed where rice fields were surveyed is eliminated during operations (Table 5.3-3).

Table 5.3-3 Rice Areas Affected Downstream of Tailings Facility

Sub-Watershed[a]	Affected (ha)	Not Affected (ha)	Flow Reduction in Affected Area[b]
A1	0.44	0.06	67%
A2	11.32	0	51%
A3	13.92	0	44%
A5	0.29	0	35%
A6	0.65	0	37%
B1	5.32	1.33	63%
B3	2.72	0	0%
C1	0	0.25	59%
C2	2.24	0	48%
C3	11.09	1.15	39%

(a) Map of watershed sub-basins provided in Volume E, Section 3.8.

(b) Reduction in flow along the mainstem of the stream at the downstream end of the reach, during operations phase.

Rice crop function depends on water height (to enter the rice water canal system) so an analysis of water volume will not directly relate to optimal growth of the crop. The decrease in actual water height, should it be more severe than expected, could be compensated through weirs to elevate the water level (farmers presently use small traditional weirs (20 to 50 cm) of wood poles and mud to manage water).

Table 5.3-4 presents the water requirements for rice compared with the predicted flows of water in each watershed sub-basin downstream of the tailings facility. Because water volume for rice is a concern to local residents and water is scarce even in baseline conditions in some areas, the following conservative assumptions were used:

- a 1 in 10 “dry year” was assumed;
- months were divided up as being dry, average or wet; and
- double the water required directly for rice growth was assumed to be needed for other agriculture, livestock use and to make up for inefficiency in canal systems supplying water to the rice paddies.

The results of the water requirements analysis indicate that although substantial declines in water volumes will occur in most of the 10 sub-watersheds with rice fields, none will have water volume shortages for agricultural use, even in a 1 in 10 dry year. This is because the volume of water needed for agricultural use is a small proportion of water available in these watercourses. The largest proportion of available water is predicted to be used in watershed B1 in November (dry season); approximately one-third of the available water is used in this case. Given that water volumes are adequate, specific water height issues can be addressed with physical on-site mitigation.

Changes in Fish Abundance

Fish and other aquatic species are caught by local populations for use as food. Therefore, effects on fish and fish habitat may also impact people. The impacts of the tailings facility on fish and fish habitat, and effects on artisanal fisheries are described in Volume E, Section 4.3.

Table 5.3-4 Tailings Basin Rice Water Requirements

	Month of the Year[a]												
	Wet	Wet	Wet	Avg	Avg	Avg	Avg	Dry	Dry	Dry	Dry	Avg	Year
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	
available water for A1a [b,c]	437,010	437,010	437,010	291,360	291,360	291,360	291,360	98,670	98,670	98,670	98,670	291,360	3162,510
water needs for A1a	1,478	440	0	10	0	674	846	982	1,036	1,242	1,326	1,204	9,238
water needs for A1na	206	62	0	2	0	96	116	136	144	172	184	166	1,284
available water for A2a - water needs A1na & A1a	803,516	804,698	805,200	536,778	536,790	536,020	535,828	185,032	184,970	184,736	184,640	535,420	5833,628
water needs for A2a	38,326	11,352	0	242	0	17,472	21,920	25,478	26,894	32,166	34,374	31,170	239,394
available water for A3a - water needs for A1a & A1na & A2a	996,160	1024,316	1036,170	690,526	690,780	672,538	667,898	215,894	214,416	208,910	206,606	658,240	7282,454
water needs for A3a	47,126	13,958	0	298	0	21,484	26,952	31,348	33,068	39,550	42,270	38,324	294,378
available water for B1a	376,560	376,560	376,560	251,040	251,040	251,040	251,040	62,640	62,640	62,640	62,640	251,040	2635,440
water needs for B1na	4,504	1,332	0	28	0	2,052	2,574	2,994	3,160	3,778	4,038	3,662	28,122
water needs for B1a	18,019	5,337	0	114	0	8,214	10,306	11,979	12,644	15,122	16,162	14,653	112,550
available water for B2 - water needs B1a & B1na	599,887	615,741	622,410	414,788	414,930	404,664	402,050	105,327	613,188	295,596	294,296	396,615	5179,492
water needs for B2a	0	0	0	0	0	0	0	0	0	0	0	0	0
available water for B3a	283,327	299,181	305,850	199,568	199,710	189,444	186,830	56,637	55,806	52,710	51,410	181,395	2061,868
water needs for B3a	9,209	2,727	0	58	0	4,198	5,267	6,122	6,462	7,729	8,260	7,489	57,521
available water for A5a - water needs for A1na,A1a, A2a, A3a, B1na, B1a, B2a, B3a	2146,282	2229,942	2265,150	1509,358	1510,110	1455,920	1442,130	458,351	453,982	437,631	430,776	1413,442	15753,073
water needs for A5a	992	294	0	6	0	452	567	659	696	832	889	806	6,194
available water for C1a	455,940	455,940	455,940	303,960	303,960	303,960	303,960	100,500	100,500	100,500	100,500	303,960	3289,620
water needs for C1na	833	247	0	5	0	380	476	554	584	699	747	677	5,203
available water for C2a - water needs C1a	693,877	694,463	694,710	463,135	463,140	462,760	462,664	156,496	156,466	156,351	156,303	462,463	5022,827
water needs for C2a	7,583	2,246	0	48	0	3,457	4337	5,041	5,321	6,364	6,801	6,166	47,363
available water for C3a - C1na-C2	975,974	981,898	984,390	656,227	656,280	652,444	651,467	219,465	219,155	217,997	217,512	649,436	7082,244
water needs for C3a	37,542	11,119	0	238	0	17,114	21,471	24,957	26,344	31,507	33,673	30,530	234,494
water needs for C3na	3,883	1,150	0	25	0	1,770	2,221	2,582	2,725	3,259	3,483	3,158	24,257
available water for A6a - all water needs above	2984,350	3103,787	3154,050	2101,626	2102,700	2025,338	2005,647	665,068	658,821	635,480	625,693	1964,693	22027,252
water needs for A6a	2,183	647	0	14	0	995	1,249	1,451	1,532	1,832	1,958	1,776	13,638

[a] Based on Hydrology calculations: three simulations completed, for dry, average and wet months; each month has been placed into the category that best fits it.

[b] Water available is equal to predicted flow levels minus needs in upstream areas. For example, available water for A3a is flow predicted into A3a minus flow usage of A1a, A1na, and A2a.

[c] Notation for watersheds: first letter (A,B,C) refers to main watershed in tailings facility, 2nd digit refers to sub-basin (higher numbers farther downstream), small “a” refers to watershed in which flows are affected by tailings facility, small “na” refers to watershed in which flows are not affected.

Assumes 50% water loss due to inefficiencies in canals, etc, thereby doubling need of the volume of water to grow the rice.

Changes in Wildlife Populations

Some wildlife species are caught by local populations for use as food. Therefore, effects on wildlife and wildlife habitat may also impact people. The impacts of the tailings facility on wildlife are described in Volume E, Section 4.2

5.3.7 Mitigation

For individuals affected directly by the project, the most important mitigation measure is the provision of additional, equivalent properties for people to relocate to. Lands for relocation are described in the relocation plan. In addition, the tailings facility is being designed to occupy the minimum feasible area of land, and the following mitigations will be applied:

- All standard safety measures will be in place, such as dam engineering to appropriate international standards, to reduce risks of impacts to downstream land users (discussed in the natural risks section, Volume E, Section 3.6).
- Water volumes flowing within the watersheds downstream of the tailings facility will be maintained at levels to support agriculture downstream (as described above and in hydrology, Volume E, Section 3.8). Water volumes and depths will be monitored; if there are declines in water depths in streams feeding rice paddy areas, assistance to local farmers in the form of improved water management conveyance systems or additional water supplies will be considered.
- Mitigation will be in place to reduce downstream impacts to Water Quality (Volume E, Section 3.10).
- Other socioeconomic mitigation and compensation measures for those directly or indirectly affected by the project will be developed, as described in the socioeconomics section (Volume E, Section 5.1).
- Tailings facility areas will be reclaimed following the completion of the project, to function ecologically in accordance with regional land use objectives, although agricultural use may not be possible (described in Volume E, Section 6 and Volume H, Appendix 7).

5.3.8 Conclusions

The project will have a large effect on land uses in the immediate area of the project due to direct disturbance of lands used for agroforestry, plantations and woodlots, rice paddies, and areas used for tavy agriculture and grazing. The re-settlement of households to other areas will be required to mitigate the effects of these impacts on livelihoods.

The project may also have effects on land use in areas surrounding the mine due to alterations to water quantity downstream of the tailings facility. These effects are difficult to define with certainty and will be monitored; mitigations are expected to largely eliminate these impacts, but if monitoring indicates that impacts are occurring, additional action will be taken. The magnitude of these impacts in socioeconomic terms are evaluated in Volume B, Section 5.1.

5.4 HUMAN AND ECOLOGICAL HEALTH

5.4.1 Introduction

The health assessment for the tailings facility area focuses on potential changes in water quality and possible associated effects on human and aquatic life health both during and after the operation stage. The potential impact on water quality resulting from effluent drainage relative to drinking water for people and livestock and on local economic activities such as crops, subsistence agriculture and fishing were evaluated. Also, aquatic and terrestrial organisms may be affected if water quality is impacted.

5.4.2 Study Area

The tailings facility study area for health assessment encompasses water bodies (rivers, ponds, streams and wetlands) within the drainage basins which may potentially be influenced by the tailings facility (Figure 7.2-3 in Volume A, Section 7, EA Methods and Study Areas).

5.4.3 Baseline Summary

A detailed description of the methods used for the screening level health assessment and its results are found in Volume K, Appendix 4.1. A short summary is provided below.

5.4.3.1 Methods and Main Results

Human Health

The baseline assessment focused on ingestion of drinking water and fish, and the potential risks to critical receptors.

Manganese was the only chemical considered of potential concern in drinking water. This arose because one sample collected during the wet season (out of 16 samples collected during the wet season and 13 during the dry season) had a concentration above the World Health Organization (WHO 2004) drinking water guidelines. The average manganese concentration did not exceed guidelines.

Levels of elements within fish tissue met recommended values for fish consumption suggesting that their ingestion as a regular food resource by people is unlikely to cause negative health effects.

Screening-level human health risk analysis of the baseline conditions related to ingestion of surface water and fish living in these waters suggest potential exposure would yield low to negligible risk.

Aquatic Health

The aquatic receptors selected for the assessment were aquatic plants, invertebrates, benthic invertebrates and fish living in water bodies in the tailings facility area.

Aluminium, copper, iron, nickel and zinc were considered of potential concern for aquatic receptors' health since their maximum measured concentrations in water and/or sediment exceeded water and/or sediment guidelines for protection of aquatic life.

Screening-level risk analysis of the baseline conditions related to surface water suggested iron and copper present potentially elevated risk levels to some aquatic biota, including invertebrates.

5.4.4 Impact Assessment

This section of the health assessment evaluates the potential adverse effects to human and aquatic health due to the operation and post-closure of the facility in combination with the baseline conditions.

5.4.4.1 Issue Scoping

The main tailings health issue captured from consultation with all stakeholders is the concern that water quality will be affected around the facility and this in turn may affect, crops, drinking water, flora and fauna.

Key questions established to address those issues are listed below. Linkage diagrams for potential impact pathways are provided in Volume H, Appendix 9.

Key Question HH-1 What Effect Will Chemical Releases From the Tailings Facility Site Have on Human Health?

Key Question HH-2 What Effect Will Chemical Releases From the Tailings Facility Site Have on Livelihood Resources?

Key Question EH-1 What Effect Will Chemical Releases From the Tailings Facility Site Have on Aquatic Life Health?

Potential impacts on terrestrial flora and fauna health are evaluated in Section 4 (Biological Assessment) in this Volume.

5.4.4.2 Key Question HH-1: What Effect Will Chemical Releases From the Tailings Facility Site Have on Human Health?

Impact Pathway

The following impact pathways were analyzed:

- between changes in water quality and human health; and
- between changes in food quality and human health.

Water Quality

Predicted water quality in the tailings area is presented in the Section 3.10, Water Quality Assessment in this Volume. Changes in surface waters (i.e., more than 10% change of some water quality parameters compared to baseline concentrations) are predicted to occur during operation and post-closure of the facility (Table 5.4-1). People in the study area depend on surface water for drinking water (Volume K, Social Appendices).

Table 5.4-1 Water Quality Parameters Predicted to Increase Due to the Tailings Facility Versus Baseline Conditions

Parameters	Watersheds											
	A1	A2	A3	A4	A5	A6	B1	B2	B3	C1	C2	C3
magnesium	X	X	X	X								
sulphate	X	X	X	X	X	X	X	X		X	X	X
manganese	X	X	X	X	X	X	X	X		X	X	X
zinc					X	X	X					
silicon							X					

Note: "Xs" represent a change of more than 10% in relation to the baseline conditions.
Watersheds are as defined in Section 3.8 of this volume (Hydrology).

Fish Quality

Some of the elements which levels are predicted to increase at the facility site can bioaccumulate in fish tissue and fish are an important food resource in the area.

Assessment Methods

Water and Fish Quality

The evaluations were conducted according to established risk assessment methods endorsed by Health Canada (HC 2003) and the United States Environmental Protection Agency (USEPA 1992) frameworks. The detailed approach is presented in the Human and Ecological Health Appendix (Volume K, Appendix 4.1). Receptors parameters and toxicity reference values used for risk estimations can also be found in that appendix.

Impact Description Criteria

The assessment criteria used for human health are the same used for the mine area (Volume B, Section 5.4).

Results

Water Ingestion Risk Results

Predicted concentrations of sulphate and zinc met applicable guidelines. Drinking water quality guidelines were not available for magnesium and silicon. Magnesium is an essential nutrient and health effects may be related to observed deficiencies (FDA 1996). Therefore potential incremental increase from 1 mg/L (baseline) to 2 mg/L (maximum predicted value) of magnesium in some of the assessed rivers was not considered a potential health issue.

There is little information available on toxicity of silicon, but studies on animals suggest that silicon may be essential in humans and most silicon compounds are essentially nontoxic when taken orally (ASN 2005). Similarly to magnesium, health problems are more likely to be related to silicon deficiency rather than its incremental dose. Therefore the potential increase of silicon levels in watershed B1 (from the baseline concentration of 4.2 mg/L to 4.8 during Year 27) did not warrant further consideration.

Average annual levels of manganese exceeded guidelines for taste during operation and post-closure of the facility but met health-based targets in all watersheds. Average background levels of manganese also exceed the taste guidelines of drinking water. For that reason the potential increase of manganese in those rivers is considered to pose low to negligible incremental health risk for the communities.

Fish Ingestion Risk Results

Potential health effects due to possible increase of magnesium and silicon in fish tissue were not considered of concern due to the reasons described above.

Dissolved sulphate was also screened out from this exposure pathway as it is does not bioaccumulate in fish and has diverse interactions and forms complexes with other dissolved substances.

Only manganese and zinc were retained for further evaluation. Fish tissue concentrations of those two metals were estimated based on annual measured (baseline) or predicted (operation and closure) levels in water, and fish bioconcentration factors. These chemicals are classified as non-carcinogenic (see carcinogenic classification of chemicals of concern in the Methodology Appendix, Volume K, Appendix 4.2). The doses via fish ingestion were then calculated and divided by benchmark doses representing acceptable risk to estimate the hazard quotient (HQ).

Human health exposure and risk estimates for the critical receptor (child) are summarized in Volume K, Appendix 4.2. Table 4.2-20. The results indicate low to negligible non-carcinogenic health risks associated with exposure to manganese and zinc due to increased fish tissue concentrations during tailings operation and post-closure.

5.4.4.3 Key Question HH-2 What Effect Will Chemical Releases From the Tailings Facility Site Have on Livelihood Resources?

Impact Pathway

Water Quality

Communities in the study area rely on water resources as livestock drinking water and irrigation of rice, manioc, beans, orchards and commercial crops and fishing. Changes in water quality could therefore affect livelihood resources.

Assessment Methods

Produce and Livestock

Concentrations of parameters that are predicted to change during tailings operations (Table 5.4-1) were screened against guidelines for irrigation water and livestock watering (South African Water Quality Guidelines, DWAF 1996a and b). Levels above guidelines were considered of concern for agricultural use.

Fish

Potential effects on fishery are related to direct effects on fish health and indirect effects such as decrease of fish food (e.g., algae, invertebrates). Those potential impacts are assessed under Key Question EH-1 (see Section 5.4.4.4).

Impact Description Criteria

The assessment criteria used for impacts on livelihood resources are the same used for the mine area (Volume B, Section 5.4).

Results

Produce and Livestock

Annual baseline and predicted (operation and post-closure phases) levels of magnesium, sulphate, manganese and zinc were compared with guideline values for irrigation water and livestock watering. Guidelines were not available for silicon.

The levels of magnesium, sulphate and zinc met the guidelines for agricultural use. Manganese was the only parameter that exceeded the South African target water quality range (TWQR) for irrigation water (0-0.02 mg/L) regarding soil sustainability for crop yield in all assessed watersheds (Tables 4.2-21 through 4.2-31 in Volume K, Appendix 4.2). It should be noted that these target values are related to plant toxicity and not food quality or potential effects on human health.

In spite of the exceedance, the increased levels of manganese are not expected to cause effects on produce for the following reasons:

- Predicted levels of manganese during tailings facility operation and post-closure ranged from 0.11 to 0.19 mg/L. That range exceeded TWQR but met South African maximum acceptable concentration for irrigation water (0.02-10.0 mg/L).
- Current manganese levels (average baseline conditions) in surface water are 0.11 mg/L and also exceed TWQR. (As mentioned in the South African document, the TWQR for manganese is based on relatively limited information and should be viewed as tentative. It was developed for fine-textured neutral to alkaline soils and the manganese toxicity depends on plant species and nutrient solutions in the irrigation water.)
- Predicted concentrations of manganese are below the maximum recommended values by the Food and Agriculture Organization of the United Nations (FAO) for irrigation water (0.2 mg/L; Ayers and Westcost 1994) and guidelines from other jurisdictions (0.2 mg/L, for any soil type, CCME 2002)

In conclusion, the operation of the tailings facility is unlikely to pose incremental risk to local community livelihoods due to irrigation and livestock watering.

Fishery

Effects on fish and fish food (algae and invertebrates) due to drainage from the tailings site were considered low to negligible (see assessment of risk to aquatic life in the next sections). Potential risks related to physical changes, e.g., river sedimentation, are detailed in the Environmental Assessment of Fish and Aquatic Resources Section in this Volume.

5.4.4.4 Key Question EH-1 What Effect Will Chemical Releases From the Tailings Facility Site Have on Aquatic Life Health?

Impact Pathway Evaluation

Water Quality

Aquatic health can be directly affected by changes in physical or chemical water characteristics. Several water quality parameters are expected to change more than 10% during tailings operation and/or post-closure. Therefore, effects on aquatic health may occur.

Sediment Quality

The benthic community can be directly affected by changes in sediment conditions. Non-benthic aquatic organisms can also be indirectly affected (e.g., decreased food resources). Levels of lead, mercury and zinc in sediment are predicted to increase more than 10% over baseline conditions during tailings operation and/post-closure (Water Quality Assessment, this Volume).

Assessment Methods

Water and Sediment Quality

The evaluations were conducted according to established risk assessment methods endorsed by the USEPA (1992) framework. Refer to the Human and Ecological Health Appendix for detailed description of the methodological approach.

Impact Description Criteria

The assessment criteria used for aquatic life health are the same applied for the mine area (Volume B, Section 5.4).

Results

Water Quality

Aluminum, copper and iron were considered chemicals of potential concern in the baseline risk assessment (Section 5.4.3) but they were not assessed further since predicted concentrations are similar to baseline conditions and no incremental risk for aquatic life is expected.

Water quality parameters which are expected to change due the operation of the facility (Table 5.4-1) were screened against South African Guidelines for Aquatic Ecosystems (1996). Alternative references were used for sulphate which is not listed in the South African document (Recommended Guideline for Freshwater Aquatic Life by Province of British Columbia, 2001). The data screening indicated that sulphate and manganese did not warrant further consideration.

No guidelines for aquatic life are available for silicon. This element is considered non-toxic and, based on recent literature, no negative environmental effects related to this chemical have been reported. Therefore this potential increase in surface waters in the study area is not considered environmentally significant or warranting further risk analysis.

Zinc and magnesium were retained for further analysis and because concentrations of zinc were above guidelines and because no guideline value is available for magnesium.

Concentrations of zinc and magnesium were then divided by toxicity reference values for algae, invertebrates and fish (Suter 1996) to calculate Hazard Quotients (HQ) (see Volume K, Appendix 4.2 for description of risk estimation of hazard quotients). The calculated HQs for each type of organism are presented in Table 4.2-32 in Volume K, Appendix 4.2.

The HQ values for magnesium towards invertebrates and for zinc towards invertebrates and fish were lower than 10 and considered negligible given the conservative assumptions employed in water quality modelling as well as the assumption of 100% bioavailability of these substances in the freely dissolved phase.

The HQs for zinc towards algae were greater than 10 and could be of potential concern. However, calculated HQ values for operation and post-closure phases are similar to the HQ for the baseline conditions. Therefore incremental risk to aquatic life due to tailings operations is unlikely to occur, and moreover, the elevated background concentration would suggest local viable aquatic biota may also have developed an increased metal tolerance which is a well-documented physiological response.

As part of the water quality assessment, predicted water quality was estimated and then simulated water samples were assessed using toxicity tests with aquatic biota (Daphnia magna) considered to be more sensitive than most aquatic biota. The results suggest predicted water quality would present no acute toxicity to aquatic organisms including fish, and based on the actual data unlikely to yield chronic toxicity as well (see Section 3.10 in this Volume for further details).

Sediment Quality

Copper and nickel were considered chemicals of potential concern in the baseline health assessment (Section 5.4.3) but they were not further evaluated since concentrations during operation and post-closure of the facility are expected to be similar to the baseline conditions.

Predicted levels of lead, mercury and zinc met sediment guidelines. Based on these observations, the incremental risk to benthic communities posed by the tailings facility site is considered low to negligible.

5.4.4.5 Mitigation

Mitigations that are applicable to human and aquatic health were addressed previously in the Water Quality Assessment, (in this Volume). Results of the health assessment suggest that additional mitigation is not warranted.

5.4.4.6 Residual Impacts

The residual impact classification on health impacts in the tailings facility area is provided in Table 5.4-2. They have been assessed as negative, low to negligible, local (limited to the watersheds directly affected by the tailings site), long-term (lasting after the site closure) and of high frequency (occurring continuously). All residual impacts are therefore of low to negligible environmental consequence.

Table 5.4-2 Residual Impact Classification for the Tailings Facility Area on Human and Aquatic Health Effects

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key Question HH-1	**What Effect Will Chemical Releases From the Tailings Facility Site Have on Human Health?**					
negative	low to negligible	local	long-term (operation and post - closure)	reversible	high	low to negligible
Key Question HH-2	**What Effect Will Chemical Releases From the Tailings Facility Site Have on Livelihood Resources?**					
negative	low to negligible	local	long-term (operation and post - closure)	reversible	high	low to negligible
Key Question EH-1	**What Effect Will Chemical Releases From the Tailings Facility Site Have on Aquatic Life Health?**					
negative	low to negligible	local	long-term (operation and post - closure)	reversible	high	low to negligible

5.4.4.7 Monitoring

No further monitoring beyond what was planned under the Water Quality assessment is warranted.

5.4.5 Conclusions

The human and ecological health assessment evaluated the potential for adverse effects to health associated with drainage from the tailings facility site in combination with baseline conditions. Human exposure to drinking water and fish ingestion and aquatic life exposure to water and sediment were evaluated as well as potential effects on changes in livelihood resources (fish, produce and livestock) due to impacts on surface water quality. Potential effects were rated as low to negligible for all receptors (people, aquatic life, livestock and produce). The assessment was based on many conservative assumptions (for explanations on the conservative approach of the assessment refer to “Layer of Safety” in Volume K, Appendix 4.2). The prediction of confidence that risk has not been underestimated can be rated as moderate to high.

5.5 TRAFFIC

The Environmental Assessment for the effects of the tailings facility on traffic is presented in Volume D, Section 5.5 in combination with the effects of the process plant on traffic in the immediate vicinity of Toamasina.

6 RECLAMATION AND CLOSURE PLAN

6.1 INTRODUCTION

Reclamation and closure of the tailings facility will be based on the following general objectives:

- Reclamation goals and objectives will be considered during design and planning of construction and operations.
- Progressive reclamation will be implemented where possible.
- Upon cessation of operations, equipment will be decommissioned and the area will be rehabilitated to allow for future land use as guided by local authorities and stakeholders.
- The reclamation and closure design will ensure that long-term physical and chemical stability is provided.

This preliminary reclamation and closure plan is a living document that will be updated throughout the project life to reflect changing conditions and the input of local authorities and stakeholders.

6.2 FACILITY CLOSURE PLANS

The tailings facility will be operated in three phases, with each phase using an operating tailings basin and a water basin. The water basin used during Phases 1 and 2 will become the future Phase 3 tailings basin, and a new Phase 3 water basin will be constructed in Year 20. Phase 1 and Phase 2 tailings basins will be closed out as part of progressive reclamation and only the Phase 3 tailings basin and Phase 3 water basin will require reclamation at final closure. The approach to closure of each facility will be the same, whether as part of progressive or final reclamation.

The tailings beach within each tailings basin will be allowed to air dry for a period of time, likely two years, and progressively revegetated to provide a stable erosion-resistant surface which may be safely traversed by humans and animals. A residual sedimentation pond will be left in place to collect sediment until the vegetation becomes well established and will likely be left as a wetlands area. Suitable drainage measures will be designed and implemented for maintaining stability during extreme precipitation events.

Decant weirs (tailings and water basins) will be in filled and incorporated within the embankment and a closure spillway, suitably armoured to prevent erosion and will be constructed to redirect flows from the tailings basin into the original valley downstream. The design will likely include gabions that will permit the growth of vegetation and establishment of a root mass while also provide sufficient erosion protection.

Detailed design of tailings basin embankments will include benching and drainage channels to facilitate runoff and reduce the potential for erosion. The final embankment raise for the Phase 3 tailings basin will occur during operations, with the establishment of permanent benching and drainage as well as vegetation cover. Thus the focus at final closure will be continuing the revegetation process.

The Phase 3 water basin will be drained and the high-density polyethylene (HDPE) liner will be removed from the basin. The embankments of the water basin will be breached and recontoured to restore drainage and mimic the natural environment, and any remaining disturbed surfaces will be revegetated.

Seepage collection ponds will be infilled and/or stabilized with vegetation and, with armouring as necessary, and surface runoff will be directed into the original valley downstream. Return pumps will be removed.

The groundwater recovery system located at the base of each tailings basin will operate for about 15 years post-closure, when groundwater modelling has predicted that elevated salt concentrations in groundwater will have subsided. The recovery system pumps and pipelines will be removed and the boreholes abandoned.

The reclaim barge will likely be salvaged for re-use at another location or for parts. Above-grade portions of pipelines, as well as pumping systems, will be removed at closure. Buried sections of pipelines will be drained and left in place, as their removal would cause unnecessary disturbance.

It is expected that transportation corridors will remain in-place for a post-closure period to facilitate site access for monitoring. Unless other users in the region have become dependent on the access the transportation corridors provide, any aggregate within the road base may be salvaged for use by others, the road surfaces will be scarified, and revegetated.

Any stockpiles created during operation of the tailings facility, most likely topsoil, will either be applied to embankments or the final tailings surfaces. If the material contains or retains topsoil characteristics it will be used in final surfacing for revegetation. Lacking these properties, the material may be used for general cover purposes. No stockpiles will remain at the site following the active closure phase.

6.3 RECLAMATION PLANS

6.3.1 Erosion Control

The following general mitigation options are available to prevent water erosion:

- salvage topsoil where feasible and store away from areas of potential erosion;
- construct temporary cross ditches to redirect surface runoff;
- construct temporary berms of imported logs, construction timbers, sandbags or other material as appropriate and available;
- construct berms with overburden in areas where topsoil has been stripped;
- construct mine roads so natural drainage patterns are not impeded and in a manner that runoff to road ditches enters natural drainage systems or contoured containment areas;
- use temporary erosion control measures such as mulches, mats, netting, or straw crimping to control erosion before establishing a protective vegetative cover;
- apply tackifiers where necessary to stabilize soils and use hydroseeders for seeding on steep slopes; and
- promptly seed exposed areas and topsoil stockpiles with a self-sustaining, erosion-controlling seed mix appropriate to the region. It is suggested that Vetiver grass (*Vetiveria zizanioides*) be planted in strips across slopes (following contour lines) (NRC 1993). Other species can then be planted between the strips of Vetiver.

6.3.1.1 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).

6.3.2 Revegetation

Revegetation of disturbed surfaces is a key restoration objective in that the vegetation provides sediment and erosion control and allows for future land uses. Currently, it is believed that the general reclamation approach is best conducted in four distinct conceptual phases, including:

- water and erosion control;
- soil preparation and revegetation;
- planting native trees; and
- inducing natural succession.

Note that decisions as to species mixes to use for re-vegetation will be influenced by guidance of stakeholders as to end use goals. End use goals, however, will need to recognize limitations associated with the nature of the tailings material, mainly its physical properties. Consultation on end-use options will occur during operations.

6.4 MONITORING

Post-closure monitoring will involve physical stability monitoring to identify evidence and/or early indications of erosion and stability issues and/or safety hazards, as well as a continuation of groundwater and surface water monitoring for the same parameters as the operation phase. The frequency of this monitoring will be determined based on the observed conditions.

7 ENVIRONMENTAL AND SOCIAL MANAGEMENT PLANS

This section provides highlights of selected mitigation and monitoring that will form part of the management plans specific for the Ambatovy Project's (the project) tailings facility. More detailed information is provided in the mitigation and monitoring sections of each Environmental Assessment (EA) discipline section. A full framework for the Environmental and Social Management Plan is provided in Appendix H, Section 6. Mitigation and monitoring plans are divided into two sections below: Section 7.1 presents activities to be carried out for key management plans during operations and Section 7.2 presents activities to be carried out for key management plans during reclamation and closure.

7.1 CONSTRUCTION AND OPERATIONS PHASE ACTIVITIES

7.1.1 Water Management Plan

Runoff from the tailings facility will be diverted to the ocean to prevent substance loading from entering downstream watercourses and water bodies during operations via runoff. A liner will be installed in the water management pond to limit seepage from the pond. Boreholes and pumps will be installed to intercept and remove tailings seepage downstream of the tailings facility from the beginning of operations to fifteen years after closure. Water quality in management ponds and in streams and water bodies downstream from the tailings facility will be monitored during operations, with emphasis on the metals of greatest concern for effects on human and ecological health. Volumes of downstream flows and suspended solids levels in these streams will also be monitored.

7.1.2 Flora and Fauna Management Plans

Tailings facility areas will be cleared progressively during operations to minimize the amount of area cleared at any one time. Flora and fauna management will focus on progressive reclamation (see below).

7.1.3 Fish and Aquatics Management Plan

When construction begins, fish will be salvaged from watercourses and water bodies being affected, for local use or sale if such use is desired. Project proponents will work with stakeholders and Malagasy fisheries experts on developing fishery management techniques.

Selected monitoring of aquatic resources downstream of the tailings facility will ensure appropriate protection is achieved.

7.1.4 Emergency Contingency Plan

An emergency response plan is being developed to limit impacts on both people and the environment if an unexpected extreme event occurs. If an extreme high rainfall event which has the potential to result in overtopping of the tailings dam occurs, residents downstream will be informed and evacuated to safe areas. A spill response plan will be designed to minimize effects on water quality, and any spill event will be followed up with monitoring until the contaminants are cleaned.

7.2 CLOSURE AND RECLAMATION ACTIVITIES

7.2.1 Water Management Plan

Natural runoff conditions will be re-established through grading and revegetation. Water management ponds and downstream streams and water bodies will be monitored until results indicate that seepage from the tailings facility will have no significant effect downstream.

7.2.2 Flora and Fauna Management Plans

Tailings areas will be reclaimed progressively as each pond phase is completed. To initiate revegetation, organic matter will be incorporated into the surface layer of the reclaimed soil profile to enhance fertility of tropical soils for reclamation. Deficient nutrients will be replaced as necessary with fertilizer amendments to allow for successful reclamation. Liming agents such as calcium and magnesium may be used to increase soil pH and reduce metal mobilities. A vegetation monitoring plan will be implemented during the initial progressive reclamation efforts during project operations, and continue until reclamation is completed to ensure that reclamation efforts are meeting targets and erosion control measures are working effectively.

7.2.3 Fish and Aquatics Management Plan

Upon closure, vegetation cover will be re-established to allow clean runoff into the downstream valleys to restore flows.