

Volume B 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

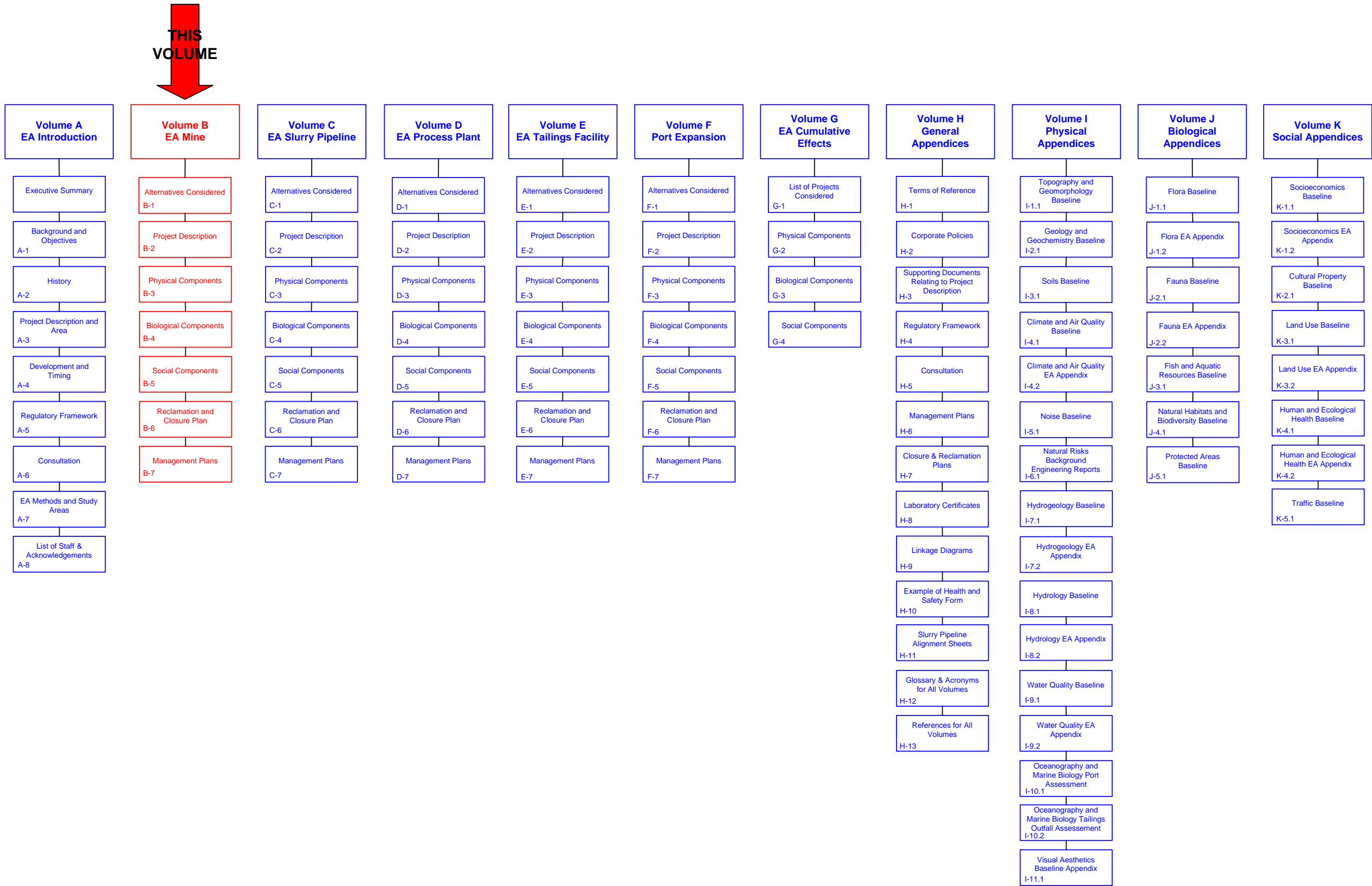


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1 ALTERNATIVES CONSIDERED

1.1 NO PROJECT ALTERNATIVE

If the Ambatovy Project is not developed, both the positive and negative impacts of the project will be eliminated. However, because the baseline case is dynamic (with long-term trends of deforestation at about 1% in the vicinity of the mine), losses of biodiversity, flora and fauna would be expected even in the no-project option. The no-project alternative is also likely to involve continued relatively slow rates of economic growth in the project areas.

The positive effects of the project, including economic benefits for employees and other stakeholders in the areas of Moramanga and Toamasina, will occur principally over a period of 30 years (construction and operations), with the potential to extend benefits past that time due to infrastructure development and other beneficial social and economic spin-offs during the course of the project. In addition, the successful development of the Ambatovy Project has the potential to encourage other future projects in support of economic development in Madagascar.

Because the residual biological impacts of the project are compensated for through offsets, they are not considered worse than they would be under the no-project option. Indeed, compared to the no-project alternative, the project has the potential for net positive benefits to biodiversity.

The physical and social effects of the project under the disciplines of topography, soils, natural risks, visual aesthetics, noise, traffic, water quality and hydrology are anticipated to be greater than no-project alternative impacts for these disciplines on a site-specific basis. Because of project mitigation, however, the residual impacts are generally low to negligible and are offset by the positive effects described above.

In summary, the Ambatovy Project is considered a better option than the no-project alternative.

1.2 WITHIN PROJECT ALTERNATIVES

Upon defining the viable ore reserves and the final mine boundaries, due consideration was given to alternatives relative to the mine area development. The objective of the mine development is to establish plans to minimize social

and environmental impacts and still be feasible from an operations and engineering perspective. Areas that offered options for development include:

- ore slurry preparation plant location;
- water storage ponds for mine drainage catchment and water storage for slurry preparation;
- water supply pipeline routing;
- overburden and waste rock stockpiles; and
- access roads.

At an early stage of design, the exact placement of each of the areas was the result of an iterative process to arrive at an optimum development plan. The primary driving force was to minimize the disturbance and preserve the residual azonal habitats with additional natural buffer zones of transitional and zonal forests.

1.2.1 On-site and Off-site Protection Areas

The project proponents strongly believe in the benefits of conserving on- and off-site habitats, and have identified two azonal conservation areas immediately adjacent to the mine (containing representative habitats of the Ambatovy and Analamay azonal forests) and one off-site azonal conservation area at Ankerato to protect. In both cases, several alternatives were considered. The protection areas at Ambatovy and Analamay were selected since they represented the largest intact habitat areas that were not absolutely vital to the success of the mine even though they overlie low grade ore. The off-site conservation area was identified from 28 potential ultrabasic formations, to be the highest-quality intact area of habitat similar in structure to the azonal habitats at the mine site (Volume J, Appendix 1.1, Attachment 2). This assessment was based on reviews of map data, an aerial reconnaissance and a field survey of the site.

1.2.2 Water Intake Alternatives

Two alternatives were considered with respect to supplying water to produce an ore slurry to allow transfer of ore via pipeline from the mine to the process plant. The first option was to use collection pond water from storm runoff exclusively, and the second option was to employ a Mangoro River water intake pipeline to supplement runoff water. The Mangoro River intake pipeline was selected in order to provide the flexibility so that downstream watersheds can always be maintained at seasonal flow levels similar to the baseline, minimizing ecological and social effects.

1.2.3 Electrical Power Systems

Alternatives for power supplies at the mine include coal-fired generation, oil/diesel-fired generation, gas, biomass, nuclear or hydroelectric power. Oil/diesel-fired power is the preferred alternative (Table 1-1).

Table 1-1 Analysis of Alternatives – Electrical Power Supply

| Alternative | Engineering | Relative-Cost | Environmental | Social |
|---|---|--|---|---|
| coal fired | moderate efficiency and availability | moderate capital, lower operating costs | moderate fuel quality, generates greenhouse gases, SO ₂ /NO _x | minimal impact potential visible stack |
| oil/diesel fired (preferred) | moderate/higher efficiency higher availability short construction phase | lower capital, moderate operating costs | higher fuel quality, generates greenhouse gases, SO ₂ /NO _x | minimal impact potential visible stack |
| gas fired combustion cycle | high efficiency higher availability no domestic gas supply | lower capital, higher operating costs | higher fuel quality, generates greenhouse gases, SO ₂ /NO _x | minimal impact potential visible stack |
| biomass | lower reliability of supply moderate logistics depending on source | higher/moderate capital, lower operating costs | potential high land use permitting generally easier | viewed often as environmentally friendly |
| hydroelectric | moderate reliability (seasonal/weather) requires transmission line from existing source longer construction phase | higher capital, lower operating costs | permitting generally easier may impact larger land base | potential displacement of people from dammed area viewed often as environmentally friendly |
| renewable (wind, tidal, wave action, solar) | lower reliability (seasonal / weather) | higher/moderate capital, lower operating costs | permitting generally easier renewable energy source | viewed often as environmentally friendly |

1.2.4 Mine Fleet Alternatives

Mine fleet vehicles will meet at least the standard or 'Tier II' based on the USEPA off-road regulatory guidelines. This alternative allows the project to meet key air quality criteria as described in Volume B, Section 3.4. Most vehicle engines are likely to be better than Tier II.

2 PROJECT DESCRIPTION

2.1 INTRODUCTION

The proposed mine is located about 15 km north-northeast of Moramanga, in Madagascar (Volume A, Section 3, Figure 3-1). Moramanga is about 120 km east of the country's capital, Antananarivo.

The mine will develop two resource areas, Ambatovy and Analamay. These mineral resources contain an estimated 190 million tonnes of mineralized material containing approximately 1.1% nickel and 0.1% cobalt. The mining rate for ore will be about six million dry tonnes per year, in order to produce approximately 60,000 tonnes of nickel and about 5,000 tonnes of cobalt annually. Overburden and low grade ore will be mined in addition to the ore of interest. Some overburden may be used for road surfacing; low grade ore may be backfilled into mined out areas or stockpiled for treatment in later years. The estimated project life for the deposit including processing of low grade, is at least 27 years.

The mine will be developed in sequence, moving across the resource, reclaiming and revegetating areas mined earlier. Detailed water management and sediment control plans are being established.

2.2 LAND PURCHASE PLAN

Mine Exploration Permit N° 459 is situated on two-thirds State land and one-third private land. The mineral deposit, mine footprint and 300 m security zone (total area 2,930 ha) are situated wholly on State land. For the purpose of creating a buffer zone encircling the mining activities, in 1997 Phelps Dodge submitted applications for a long term lease over an area of 6,900 ha.

On September 11, 2003, the proponent informed Land Registry Authorities of the intention to restart the project and finalize the Long Term Lease applications.

The proponent has identified the plots of land to be purchased in the area of the mine.

Approximately 40 ha is required for a pump station on the eastern bank of the Mangoro River. The planned site is situated on State land. A long term lease will be based on the Mine Site contract terms.

The water pipeline (about 23 km) traverses 8 privately owned plots and 7 state owned plots. A Right of Way will be negotiated with the respective owners. Compensation will be negotiated in the event of damage or destruction of property.

2.3 INFRASTRUCTURE

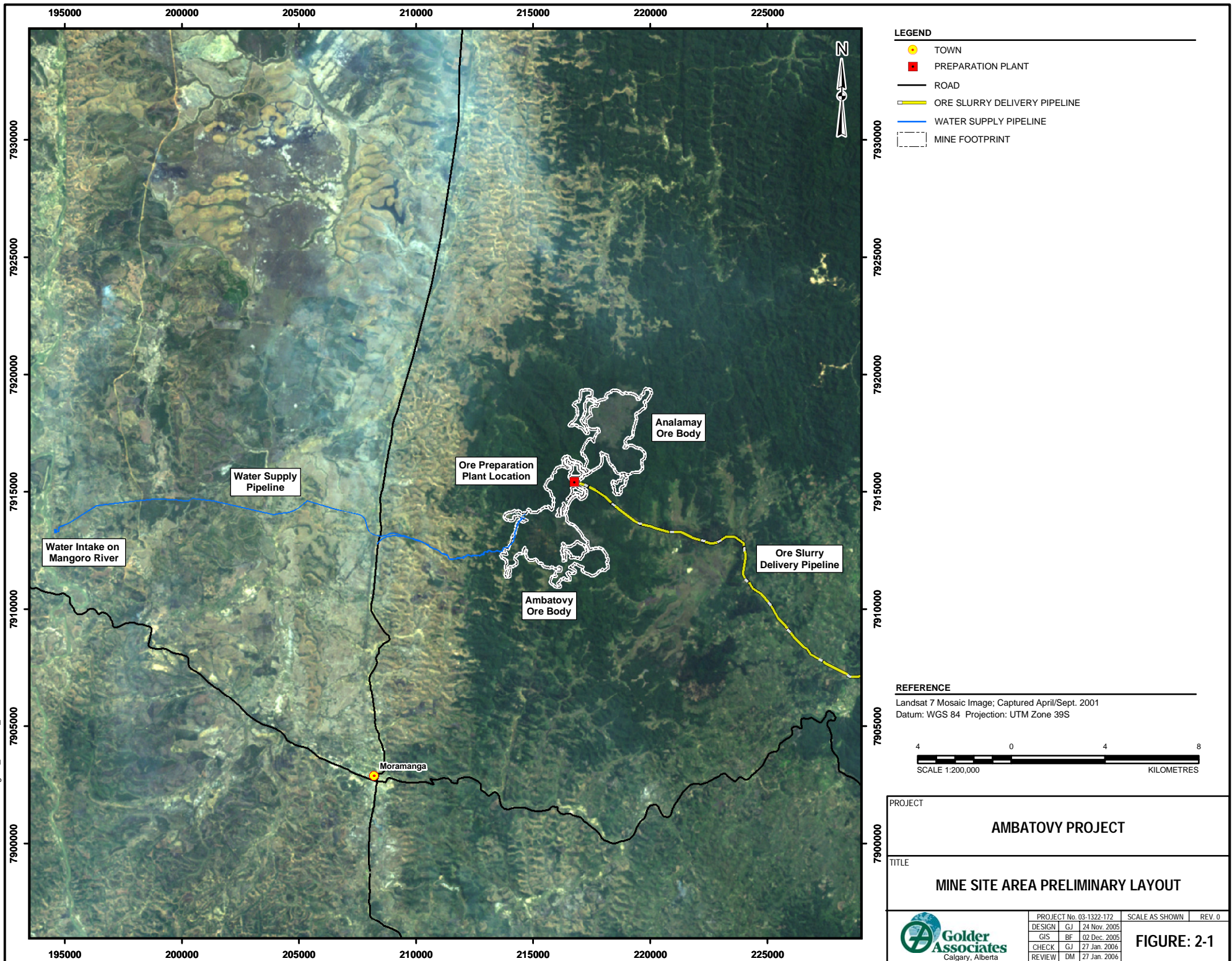
Figure 2-1 presents the general layout of the mine infrastructure. Water supply to the mine for ore processing will be from the Mangoro River, about 20 km west of the site. The maximum design flow will be 1,000 m³/hr although the nominal required rate will be much less. The expectation is that a significant quantity of the water required will be supplied by surface water collection ponds in the mine area. Power requirements for the mining and ore processing facility will be supplied by diesel-generated power plants located at the mine site.

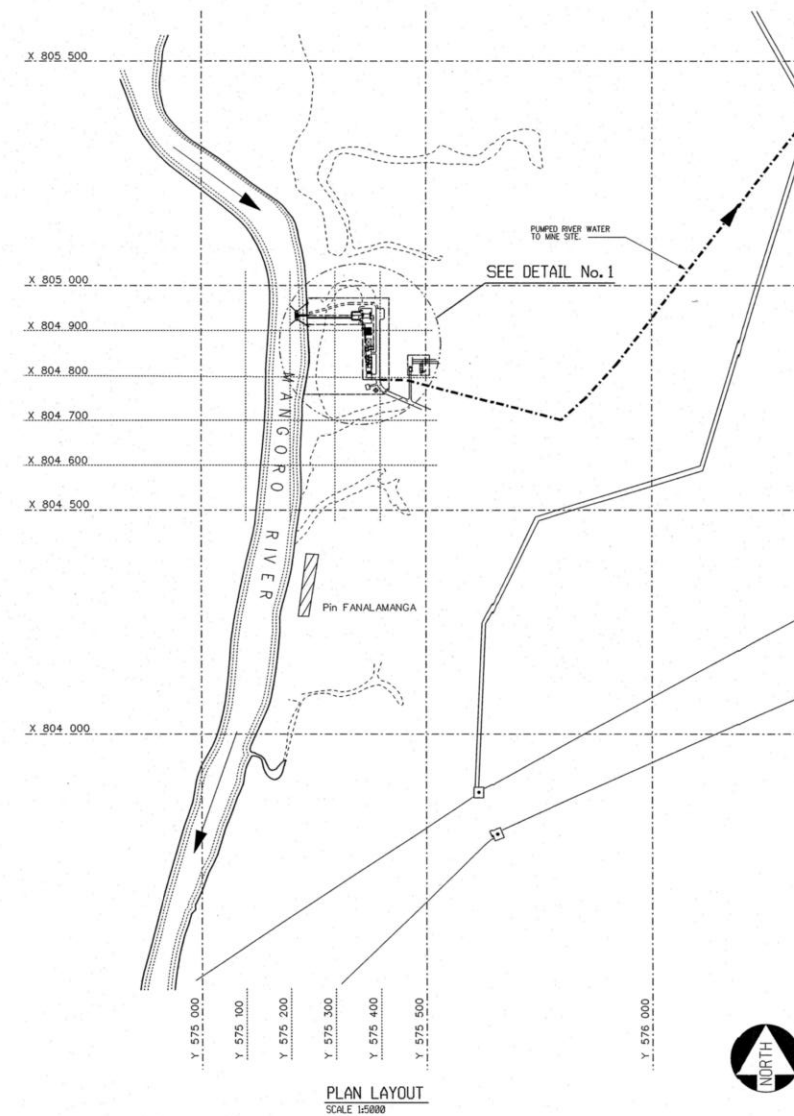
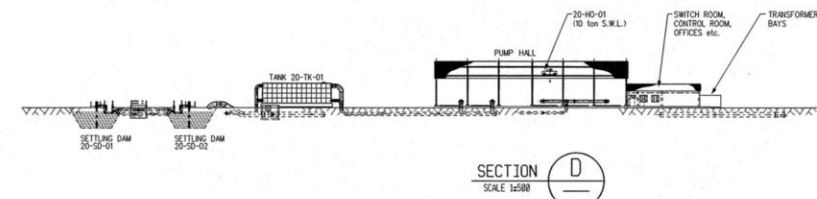
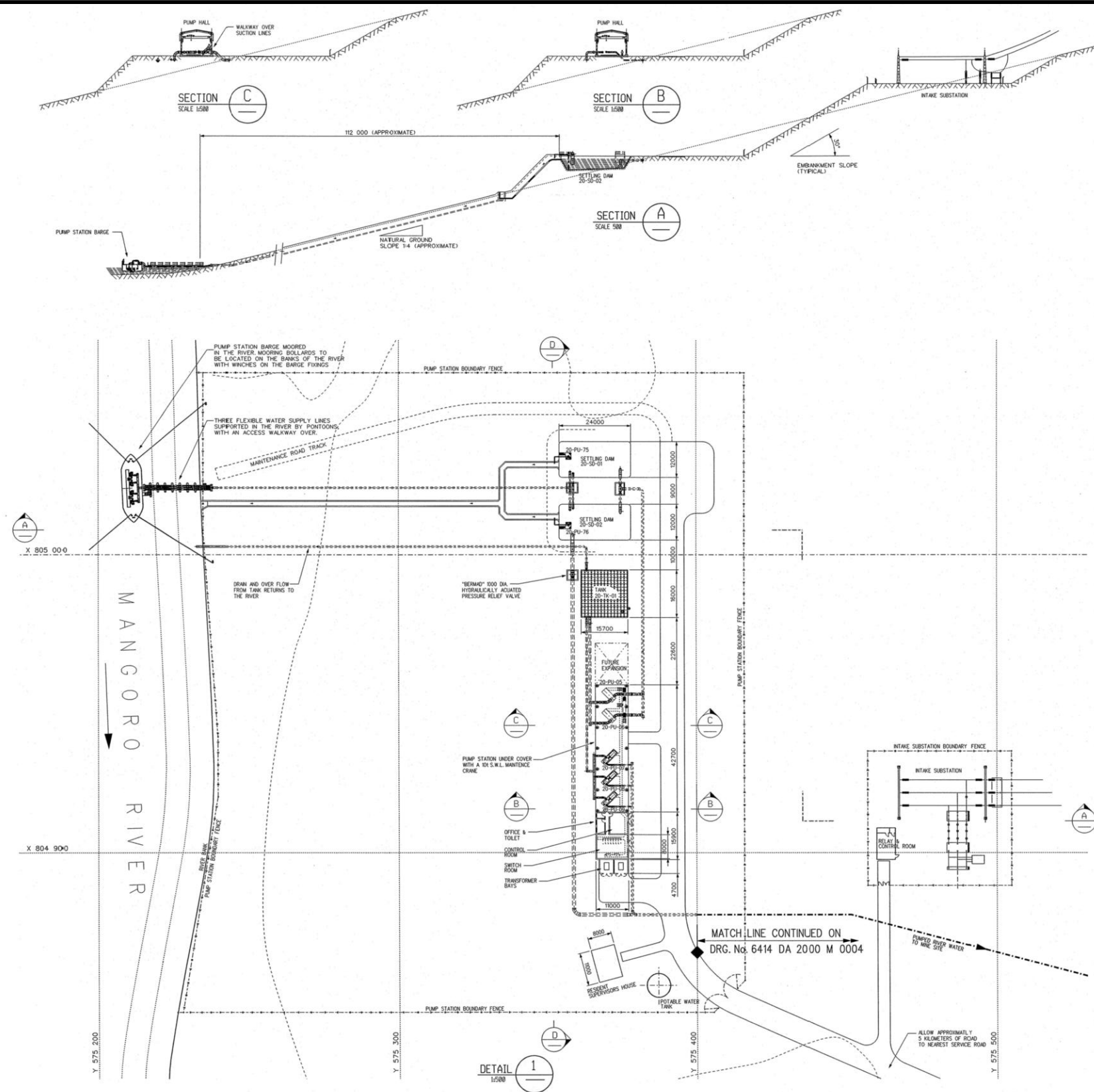
Figure 2-2 presents the general layout of the river intake facility. Figures 2-3 and 2-4 present the general arrangement of the runoff collection ponds and the conceptual water balance.

A fresh water pipeline corridor will be established from the river intake facility to the mine area. The pipeline will be 600 mm in diameter, 23 km long and will be buried.

The existing road infrastructure in the region consists of Route Nationale (RN) 2 (asphalt and paved) and RN44 (first 20 km recently asphalted) highways. An access road from RN44 to the mine site was established earlier, and this road will be further upgraded. The majority of the supplies transported to the mine site will be through the road system. The existing railway line from Toamasina to Moramanga and through to Antananarivo will also be considered for material transport.


I:/2003/03-1322/03-1322-172/mxd/General/Fig2-1_MineSite_95x11.mxd

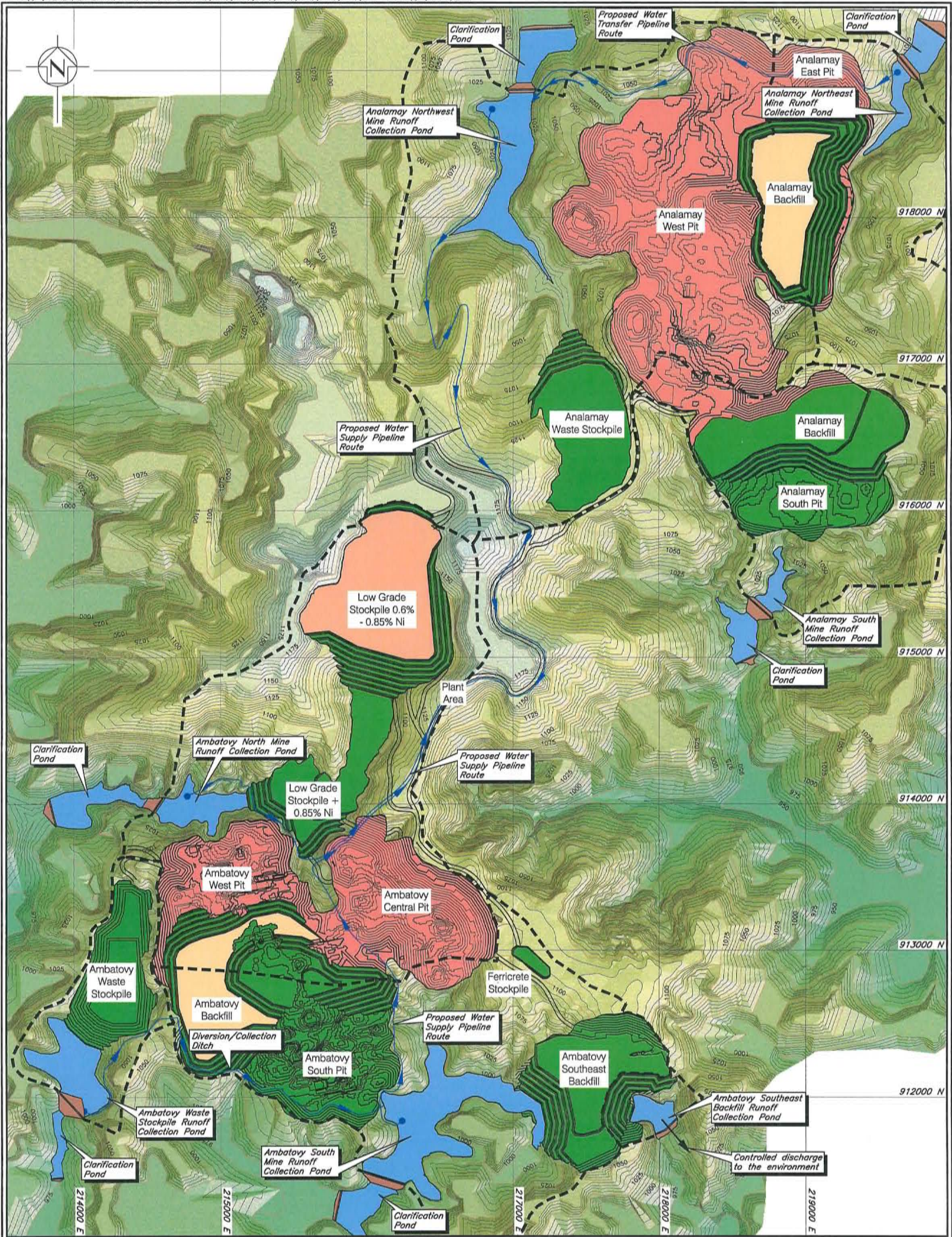




REFERENCE

ORIGINAL DRAWING PREPARED BY MURRAY & ROBERTS ENGINEERING SOLUTIONS LIMITED
DRAWING NUMBER 6414DA2000M0002.DWG

| | | | | | |
|---|--|--------------------------------------|-----|-----------------------------|----------------|
| PROJECT | | AMBATOVOY PROJECT | | | |
| TITLE | | MANGORO RIVER PUMP STATION LAYOUT | | | |
|  | | PROJECT 03-1322-172.8400 | | FILE No. Raw Water Pump Stn | |
| | | DESIGN | GJ | 06/07/04 | SCALE AS SHOWN |
| | | CADD | PSR | 06/07/04 | REV. 0 |
| | | CHECK | MR | 06/07/04 | FIGURE: 2-2 |
| | | REVIEW | DM | 07/01/06 | |



LEGEND:

- Proposed Pond Area
- Active Mining Area
- Active Stockpile Area
- Watershed Divide
- Approximate location of pump
- Proposed Pipeline Route
- Possible Pipeline Route from Analamay Area
- Active Waste Dump Area
- Rehabilitated Area

NOTES:

- Topography and mine plan layout shown provided by IMC dated Sept. 29, 2004, and represents Year 20.
- Coordinates are in UTM.
- Contour interval is 5m.
- Limits of ponds and embankments are approximate and may change.



AMBATOVY PROJECT

MINE RUNOFF CONTROL AND WATER SUPPLY FACILITIES

MINE AREA LAYOUT

YEAR 20

Knight Piésold

CONSULTING

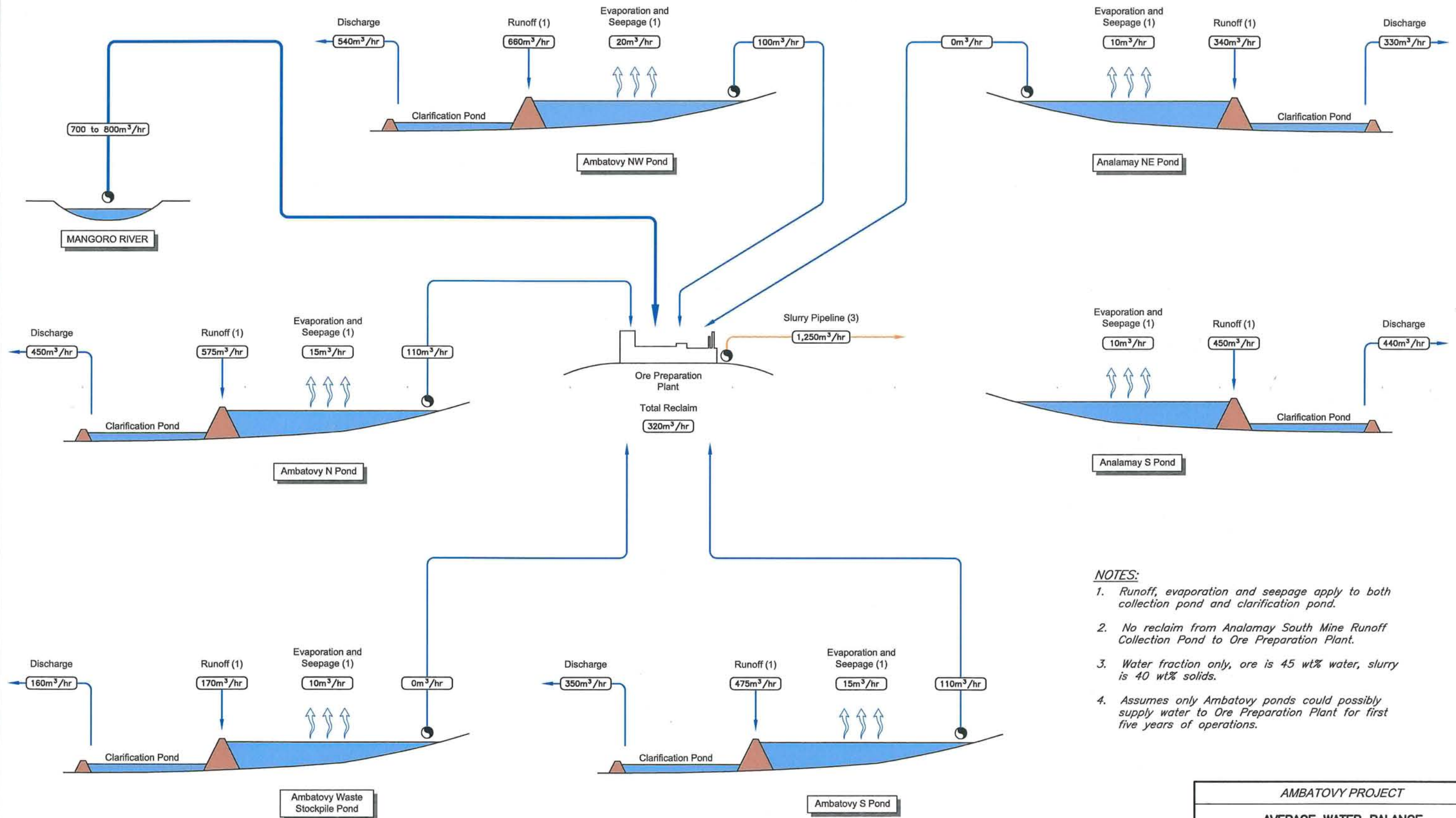
P/A NO.

REF.

REV.

NB301-00116/4

FIGURE 2-3



NOTES:

1. Runoff, evaporation and seepage apply to both collection pond and clarification pond.
2. No reclaim from Analamay South Mine Runoff Collection Pond to Ore Preparation Plant.
3. Water fraction only, ore is 45 wt% water, slurry is 40 wt% solids.
4. Assumes only Ambatovy ponds could possibly supply water to Ore Preparation Plant for first five years of operations.

| AMBATOVOY PROJECT | | | |
|--------------------------------------|---------------|---------|------|
| AVERAGE WATER BALANCE MINING AREA | | | |
| Knight Piésold CONSULTING | P/A NO. | REF. | REV. |
| | NB301-00116/4 | N5-0758 | 0 |
| FIGURE 2-4 | | | |

2.4 CONSTRUCTION

Water for the construction phase will be supplied from existing streams on site, using skid-mounted pumps. The water will be delivered to the mine site through temporary piping. The water will be stored in above-ground tanks and purified and chlorinated as necessary for construction and drinking purposes.

All surface water will be directed to drainage channels fitted with silt traps and directed to the nearest water course.

The detailed layout for the construction camp will be prepared to accommodate the approximately 600 skilled workers, artisans, supervisors and general labour. The accommodation and wash houses will be portable and are to be partially dismantled upon completion of the project execution phase. Additional facilities will be dining rooms, kitchen, refrigeration, dry storage, television and games room and telecommunication kiosks. Camp administration facilities will consist of a reception area, security offices, post office, induction lecture room, tuck shop and internet café.

All roads and services, including telecommunication ducting, electrical reticulation and area lighting will be provided. The camp will be situated near the ore processing plant. Potable water will be supplied from the plant site to tanks at the camp. Before being stored the water will be circulated through the water treatment facility. Sewage will be collected in holding tanks and septic tanks, which will be serviced on a regular basis.

Laydown areas for contractors will be provided as terraced areas complete with services located at central points as far as practically possible. Contractors will supply their own equipment and facilities as required to execute their work, in accordance with the terms of their contracts. Construction roads will be gravel roads. A dust suppression program will be implemented.

2.5 MINING METHOD

Mining at Ambatovy and Analamay will use hydraulic back hoe or front shovels and conventional haulage trucks to mine from the open pits and deliver ore to the hopper at the slurry preparation plant. The material to be mined is all laterite, which is completely weathered, and consequently has little rock strength. Blasting will not be necessary as the shovels will be able to dig the material without blasting.

2.6 PIT DEVELOPMENT

The initial pit development will be in the west Ambatovy area. Pre-production stripping is not very significant since the ore body is only a few metres under the surface. However preparation will be required for the mine so that haulage roads will be in place, and the mine will be ready to start delivering ore to the hopper, when required for start-up. The tonnage of pre-production stripping is estimated at about 100,000 tonnes. Annual ore production will build up over time to 6 million tonnes per year. Annual stripping requirements will vary from year to year, and average about 3 million tonnes per year.

Laterite ores by their nature have a high moisture content. For the Ambatovy and Analamay ore bodies, the ferralite ore is estimated to contain an average of approximately 45% moisture (by weight). The dry density will be about 1 tonne per cubic metre.

Mine development will start about six months prior to plant start-up.

2.7 MINE OPERATIONS

A mine plan has been developed to mine both the Ambatovy and Analamay deposits. The initial pit will be developed in west Ambatovy. This pit will be expanded in push backs of about 200 m, until most of the west Ambatovy pit has been developed. Progressive reclamation will occur throughout mine development.

Expansions to other mine areas will follow; this will include the central and southeast Ambatovy areas and the Analamay pit.

During the mining operation four products will be mined. These will include ore which will be delivered to either the process plant hopper or the ore stockpile. Two low-grade products will also be mined: low-grade ore and marginal-grade material. These will be stockpiled in conveniently located stockpiles, for later retrieval and processing. The fourth material will be waste rock. In most cases this will be laterite, but the grade of nickel will be too low to consider for processing.

The mine areas will be de-watered as required. De-watering will be necessary because of the heavy rainfall in the area and to a lesser extent because of groundwater inflow into the pits. Water from the open pits will be collected in sedimentation ponds, and allowed to settle before release to existing streams.

However, highly affected active pit sump water will be preferentially routed to the slurry plant rather than the collection ponds.

When an area of the open pit has been mined out it will become available for waste backfilling and/or use for low-grade storage.

The laterite material, which makes up the ore bodies, has a high moisture content, and is soft by nature. To allow for haulage truck traffic and other equipment, it will be necessary to plate the roads and benches with crushed rock. When available the ferricrete cap rock will be used, and a quarry will also be developed to supply the necessary material. The quarry will be located outside the mine areas, probably on the road between Ambatovy and Analamay.

2.8 MINING EQUIPMENT

The main mining equipment will consist of a fleet of hydraulic shovels and haulage trucks. The approximate fleet of equipment is summarized in Table 2.7-1.

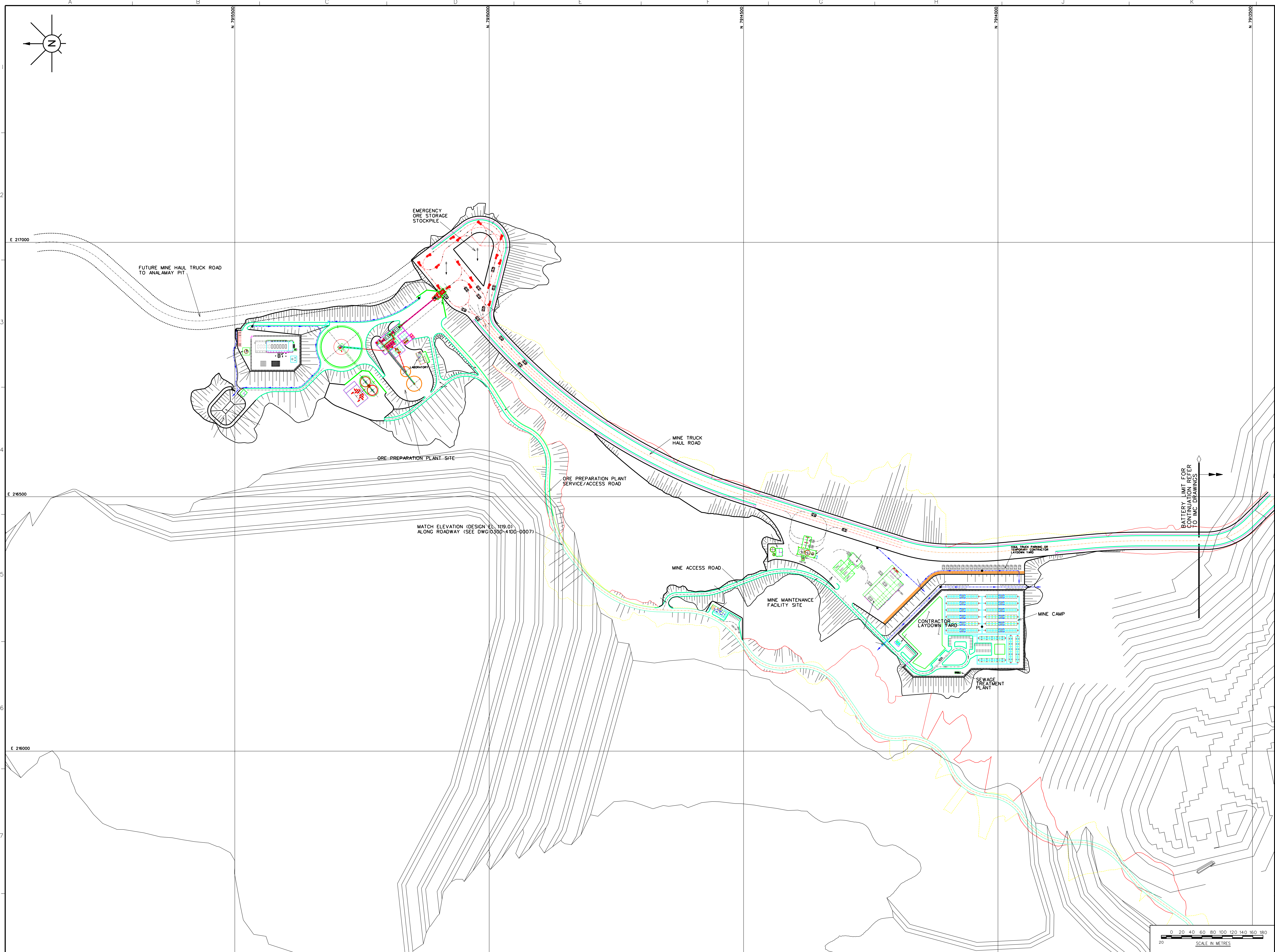
2.9 ORE PROCESSING PLANT

Figure 2-5 presents the general layout of the ore processing plant. This facility will receive the ore, prepare a slurry, screen the slurry, thicken the slurry to about 40% solids and pump the slurry into the slurry pipeline.

2.10 QUARRIES

One or more will be required to supply crushed rock for the mining operations. The effects of such operations will be assessed in an addendum to this EA.

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LEGEND:
LEGENDE:

1. BUILDING
BÂTIMENT

SHELTER
ABRI

STRUCTURE
STRUCTURE

NOTES:

CONTOURS ARE FROM MAPPING SUPPLIED BY GEOPRACTICA.
REFERENCE GRID SHOWN IS BASED ON UTM
GLOBAL CO-ORDINATE SYSTEM.

NOTES:

COURBES DE NIVEAU BASÉES SUR LA CARTOGRAPHIE
FOURNIE PAR GEOPRACTICA. COORDONNÉES DE RÉFÉRENCE
SELON SYSTÈME DE PROJECTION UNIVERSELLE UTM.

FIGURE 2-5

Ambatovy

SNC-LAVALIN
Engineers & Constructors

| | | | |
|---|----------------|-----|----------|
| DESIGNED <i>CONÇU</i> | E. MARKOULAKIS | EM | 06/02/10 |
| DRAWN <i>DRAWN</i> | D.P. LOW | DPL | 06/02/10 |
| CHECKED <i>VERIFIÉ</i> | W. PALMER | | |
| APPROVED LAY ENG <i>APPROUVÉ LAY ENG</i> | W. PALMER | | |
| APPROVED ENG MAN <i>APPROUVÉ ENG MAN</i> | | | |
| APPROVED AREA MAN <i>APPROUVÉ AREA MAN</i> | | | |

TITLE:
LAYOUT FOR ORE PREPARATION PLANT,
MINE MAINTENANCE & CAMP FACILITIES
*PLAN D'IMPLANTATION DE L'USINE DE PRÉPARATION DE MINÉRAUX,
DES INSTALLATIONS DE LA MINE ET DES BASES VIES*

| | | | | | |
|-------------|------|-------|------|----------------|-----------------|
| PROJECT NO. | AREA | DISC. | DOC. | DRAWING NUMBER | REVISION NUMBER |
| 334457 | 0300 | 4E | DD | 0001 | PA |

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2.11 WASTE MANAGEMENT

A dedicated landfill will be constructed as part of the project, to be used for domestic waste. Procedures will be developed to minimize waste generation and to ensure that all waste is appropriately managed (Volume H, Appendix 6). Any hazardous waste will be properly collected and stored prior to treatment and disposal. Waste hydrocarbons (such as used oil) will be incinerated within a dedicated on-site incinerator.

Table 2.7-1 Mine Equipment

| Type | Quantity | Size |
|-------------------|----------|----------------------|
| hydraulic shovels | 3 | 12-13 m ³ |
| haulage trucks | 15 | 100 t |
| backhoes | 2 | 4-5 m ³ |
| haulage trucks | 4 | 50 t |
| graders | 2 | 16 foot |
| track dozers | 3 | D-9 equivalent |
| track dozers | 2 | D-7 equivalent |
| rt dozer | 1 | 834 equivalent |
| loader | 1 | 992 equivalent |
| loader | 1 | 988 equivalent |

3.1 TOPOGRAPHY AND GEOMORPHOLOGY

3.1.1 Introduction

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

3.1.2 Study Area

The mine Local Study Area (LSA) for topography and geomorphology is the same as the terrestrial study area presented in Volume A, Figure 7.2-1. It includes the mine and water intake pipeline disturbance areas, plus a 500 m buffer around these areas in all directions. The LSA also includes the Torotorofotsy Wetlands and the basin within 500 m of these wetlands.

3.1.3 Baseline Summary

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

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

The geomorphology of the western part of the mine area is characterized by rolling hills and alluvium-filled valleys. The eastern part of the mine area includes a portion of the Torotorofotsy Wetlands. The geomorphology of this wetlands system is characterized by rolling hills and alluvium-filled valleys. The valleys have been partially closed off, resulting in thick depositional sequences of alluvial material.

Based on a qualitative analysis of the landscape, two relatively unusual features are located in the LSA:

- the ore bodies of Ambatovy and Analamay, capped by a thick ferricrete crust on the plateaus; and
- the Torotorofotsy Wetlands, which constitute the largest and most intact marsh in eastern Madagascar (BirdLife International Website: 2003).

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 Mine Have on Topography and Geomorphology?

The 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-mine topography was compared qualitatively with post-mine topography.

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

Project design will allow direct impacts of the mine development to avoid the Torotorofotsy Wetlands.

During construction, operations and closure, erosion control measures will be applied as described in Volume B, 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 mine features and mitigate siltation in downstream basins. This will be particularly important to mitigate effects on the Torotorofotsy Wetlands and 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 previously reclaimed areas.

3.1.5.4 Results

The ore bodies and other more regionally typical landscape features will be affected by the project. Over the course of construction and operations, a variety of landscape features including stockpiles, pits, linear access routes, drainage ditches and drainage ponds will be constructed, altering local topography.

During mine development, average highwall slopes (up to 50 m high) will be between approximately 22 degrees and 27 degrees; benches (6 m high) will average 27 degrees. Overall, slopes around active mines are expected to average about 20 degrees. Final slopes including beach angles are being redefined. Excavations will reach maximum depths of about 50 m below existing topography in some areas. The active mining area will have a relative elevation difference of up to 150 m between its lowest and highest points.

At the time of reclamation, benches will be removed to create more regular slopes. The project reclamation process will establish several new landforms. These include reclaimed waste rock disposal areas, pit lakes and linear corridors.

3.1.5.5 Impact Analysis

Residual Impacts

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

Project design and mitigation will fully mitigate the potential for topographic effects on the Torotorofotsy Wetlands.

The existing topography of the mine LSA is hilly with relatively steep slopes, except at the western end of the water intake pipeline corridor and in the immediate vicinity of the Torotorofotsy Wetlands. The areas affected by topographic change due to mining include plateau areas, steep valleys and ridges with slopes ranging from flat to about 45 degrees.

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 underlying geomorphology slope during short-term construction | erosion control; water management; stable slope engineering | low magnitude/short-term modification of ore bodies and adjacent topography |
| operations | removal and disturbance of important topographic features important for social or biological reasons (ore body formations) changes in the landscape and underlying geomorphology slope 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 ore bodies and adjacent topography |
| closure | changes in the landscape and underlying geomorphology slope which may represent important issues over the long term to stakeholders and biodiversity | erosion control; water management; stable slope engineering; full reclamation | low magnitude / long-term modification of ore bodies and adjacent topography |

Mining activity will have a direct impact on the landscape and underlying geomorphology within the ore body areas, with the creation of open pits, waste areas and a pond system. Some impacts will be temporary (medium-term), because temporary stockpiles will be removed and some pit areas will be backfilled during the operations and closure phases. Other impacts are long-term, because mine landscape features different than the baseline landscape will remain beyond the closure phase.

The magnitude of the changes are considered low during construction, as relatively small areas will be altered during this period. The magnitude of changes are considered moderate during operations, because changes in topography are greatest during the operation of pits and the maximum sizes of stockpiles occur during this period. The magnitude of the change following

closure is considered low because of the benefits of reclamation; the existing landscape contains steep, rolling topography that is not greatly different than the altered mine topography, given the successful implementation of mitigations including erosion control and slope stability engineering.

Slopes of mining 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 Mine Have on Topography and Geomorphology? | | | | | | | |
| construction | negative | low | local | short-term | no | medium | negligible |
| operations | negative | moderate | local | medium-term | no | high | low |
| closure | negative | low | local | long-term | no | low | low |

Prediction Confidence

The baseline status of topography in the LSA is well understood, and detailed information about the future landscape of the mine area has been made available through closure planning. However, impact ratings are also dependent on the success of the mitigations proposed, including erosion control and slope stability engineering under challenging conditions. Overall, the prediction confidence for this assessment is considered medium.

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 B, Section 6.

3.1.5.6 Conclusions

Following mitigation, the mine will have a negligible environmental consequence for topography during the construction phase and low environmental consequences for topography during the operations and closure phases. Implications of changes to topography and geomorphology for other disciplines are addressed in other sections of this report. The effects of closure-phase impacts on watersheds are addressed in the hydrology section (Volume B, Section 3.8).

3.2 GEOLOGY AND GEOCHEMISTRY

3.2.1 Introduction

This section discusses impacts on geology and geochemistry for the mine development of the Ambatovy Project (the project). Changes in geochemistry are not assessed as direct residual impacts in themselves, but are rather used in the water quality Environmental Assessment (EA) (Volume B, Section 3.9).

The study area for geology and geochemistry is the same as the terrestrial biology study area shown in Volume A, Section 7, Figure 7.2-1.

3.2.2 Baseline Summary

3.2.2.1 Geology

The regional geology for the areas surrounding the mine includes Precambrian-aged (4.5 billion years ago to 570 million years ago) metamorphic rocks and Palaeozoic to Tertiary-aged (570 to 2 million years ago) intrusive rocks.

Intrusive rocks of the ore bodies are from the Cretaceous Period (136 to 65 million years ago). The dominant feature of the regional geological setting of the project is a north-south striking belt of gneisses and migmatites. These rocks form part of the high-grade metamorphic rocks that underlie the eastern two-thirds of Madagascar. A large intrusive, known as the Amtampombato Complex, believed to be of Cretaceous age, cuts the gneissic terrain, and dominates the geological setting of the project.

The Amtampombato Complex intrusive is elliptical in shape and oriented northwest-southeast with the main axis some 12 km in length and the shorter axis about 7 km in length. The complex is composed mainly of gabbroic and syenitic rocks, and two smaller ultrabasic bodies. This area of the proposed mine is an outcrop of nickel-rich ultrabasics. The Ambatovy deposit lies towards the southern margin of the complex, and the Analamay ultrabasic deposit is located at the eastern margin of the complex. The ultrabasic rocks of this complex are more concentrated in nickel relative to other rocks.

Since the ore bodies are exposed on an uplifted ridgeline, they have been subjected to intense weathering from the tropical conditions present in Madagascar. The resulting laterite layer averages about 50 m in thickness. The laterite can be divided into three zones: ferricrete, ferralite and saprolite.

The ferricrete is a surficial layer that forms a several metre-thick hard, rock-like crust over the top of the deposit. Beneath the ferricrete lies the ferralite, which is a reddish-brown clay-like layer comprising the bulk of the economic ore. This layer averages 40 m in thickness. The saprolite layer is the transitional zone where the rock is neither fresh parent material nor is completely altered into the clay-like ferralite.

3.2.2.2 Geochemistry

A geochemical characterization program was performed on ore and waste rock samples from the Ambatovy and Analamay deposits. 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 materials when exposed to the environment; and
- the potential of these materials to impact surface water and groundwater quality by leaching chemical constituents.

Two geochemical characterization programs were conducted, both in support of Environmental Assessments. The first took place in the late 1990s on behalf of Phelps Dodge Corporation (PD). The second effort was completed on behalf of Dynatec as part of the current EA. The results from both investigations were combined. In total, sixteen samples were submitted for geochemical characterization.

The geochemical characterization programs conducted by PD and Dynatec were very similar in scope, and included the following:

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

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

The PD and Dynatec samples submitted for geochemical characterization are listed in Table 3.2-1.

Table 3.2-1 Sample Characteristics and Description

| EA | Sample ID | Material Category | Deposit |
|---------|---------------------------------|--------------------------|----------|
| PD | G | ferricrete and grenaille | Ambatovy |
| Dynatec | FT-Am FB-Am | ferralite | Ambatovy |
| PD | FER NFER | | |
| PD | AFER | bauxitic material | Ambatovy |
| PD | KAO | kaolinitic clay | Ambatovy |
| Dynatec | LMS-Dy | low-Mg saprolite | Ambatovy |
| PD | LMS-PD | | |
| Dynatec | SAP-Dy | saprolite | Ambatovy |
| PD | SAP-PD Pit 8 SAP Hard SAP | | |
| PD | Bedrock | bedrock | Ambatovy |
| Dynatec | FT-An | ferralite | Analamay |
| | FB-An | | |

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

The geochemical testing program completed by Dynatec and PD on ore body samples resulted in the following findings.

The QA/QC procedures and standards followed by SGS Lakefield Research and Dynatec Technology Services are described in Volume I, Section 2.1.

Although the sixteen samples generally appear to be representative of their respective lithologies, the total number of samples analyzed is small, however many are represented by composites. Most lithologies recognized by PD and Dynatec are represented by one or two samples

The chemical compositions of the four Dynatec Ambatovy samples generally are similar to their closest analogues in the PD data set. The Analamay samples are similar to their Amabatovy equivalents. The PD program did not include any samples from the Analamay deposit. The results from the mineralogical analysis indicate that the majority of minerals present in the stratigraphic sequence of the Ambatovy ore deposit are oxides and hydroxides, especially in the upper portions of the stratigraphic profile. All minerals identified are typical of the weathering profile and various stratigraphic units in nickel laterite deposits.

Based on the acid base accounting results, ore body materials are not expected to be acid generating due to sulphide oxidation, although some leachates may be slightly acidic by nature. Long-term testing of these materials to evaluate transient processes such as sulphide oxidation is therefore not considered warranted.

Leach testing demonstrates that the leachability of the samples generally is low. However, most materials appear to have the capacity to leach chromium, in particular the saprolite. Release of nickel and iron appears to be less prevalent, but may occur for certain types of saprolite, ferralite and bauxite. Bedrock is unlikely to have an adverse environmental impact. Leachate concentrations may vary considerably, and expected relationships between pH and metal leachability are not always observed.

Sequential leach testing demonstrates that the leachability of chromium, nickel and iron may persist over time. Long-term testing would be required to further evaluate the longevity of this leaching behavior.

Chromium, nickel, and iron concentrations in certain leachates exceed Malagasy and/or World Bank open pit mining effluent standards (Volume I, Appendix 2.1). However, due to the limited ability of static leach tests to simulate ambient site conditions, this does not imply that such exceedances will indeed be observed on-site. For instance, the attenuation potential of certain lithologies identified during the PD adsorption study 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

There is one valid impact pathway for geology: the project will result in a removal of economic geologic resources from the mine area. This impact is discussed qualitatively.

There is one valid impact pathway for geochemistry: the project will result in exposure of rock surfaces from which metals may leach, resulting in effects on water quality.

The linkage diagram for geology and geochemistry is provided in Volume H, Appendix 9.

Derivation of Input Water Qualities for Mine Water Quality Model

The Mine Water Quality Model is used to predict potential water quality impacts to the receiving environment (Volume B, Section 3.9). The model consists of several catchments in which mine facilities contribute runoff. For each of these facilities, an input water quality was developed from available geochemical information. This section describes the derivation of these input water qualities.

Derivation of Input Water Qualities

The various facilities included in the model are as follows:

Ambatovy:

- waste stockpile;
- west pit;
- south pit;
- southeast pit;
- ferricrete stockpile;
- low grade stockpile; and
- ore stockpile.

Analamay:

- waste stockpile;

- west pit;
- east pit; and
- south pit.

In collaboration with technical staff from Dynatec, the major lithologies represented in each of these facilities were identified during operation and post closure. These lithologies include ferralite, ferricrete and low magnesium saprolite (LMS). The various proportions of these lithologies are presented in Table 3.2-2.

Table 3.2-2 Lithology Proportions in Mine Areas

| Ambatovy | Composition | |
|----------------------|-----------------------|----------------|
| | Operational | Post Closure |
| waste stockpile | 100% ferralite | 100% ferralite |
| west pit | 90% ferralite/10% LMS | 100% ferralite |
| south pit | 90% ferralite/10% LMS | 100% ferralite |
| southeast pit | 90% ferralite/10% LMS | 100% ferralite |
| ferricrete stockpile | 100% ferricrete | not present |
| low grade stockpile | 100% ferralite | not present |
| ore stockpile | 100% LMS | not present |
| Analamay | | |
| waste stockpile | 100% ferralite | 100% ferralite |
| west pit | 90% ferralite/10% LMS | 100% ferralite |
| east pit | 90% ferralite/10% LMS | 100% ferralite |
| south pit | 90% ferralite/10% LMS | 100% ferralite |

To assign water qualities to each of these facilities, results from short-term leach testing were used. The leach test conducted was the Synthetic Precipitation Leaching Procedure (SPLP), which simulates interaction between a solid material and meteoric water. These results represented the only data available that could be used to evaluate the environmental stability (i.e., leaching behavior) of the various lithologies. For ferricrete and LMS, one SPLP result was available for each lithology. For ferralite, SPLP testing had been conducted on shallow and deep ferralite samples from Ambatovy and Analamay. It was assumed that the ferralite in the mine facilities would consist of equal proportions of shallow and deep ferralite.

Where necessary, SPLP solutions were “mixed” mathematically to represent the relative proportions of lithologies present in mine facilities. The SPLP results

and mixtures were then subjected to geochemical modeling to account for geochemical controls. The geochemical model used in this study was PHREEQC Version 2.8 (Parkhurst and Appelo, 1999), an equilibrium speciation and mass-transfer code developed by the United States Geological Survey (USGS). This model has the ability to simulate the pertinent processes occurring in aqueous solutions, such as precipitation/dissolution of selected solids, redox reactions, evaporation, atmospheric interaction, and adsorption of metals. Geochemical controls accounted for in the modeling of the input solutions included equilibrium with atmospheric carbon dioxide, mineral precipitation, and adsorption. Redox conditions of 600 millivolts (mV) were assumed, which represent typical conditions for waters in equilibrium with the atmosphere.

Uncertainties

Use of the SPLP results requires the important assumption that the SPLP results are representative of leaching under ambient conditions. In reality, short-term, single-stage leach tests often are limited in their ability to simulate ambient behavior. This is due to several factors, including the grain size reduction required for the SPLP test, a solution to solid ratio (20 to 1 by weight) that is almost certain to be higher than that in the field, and the enhanced contact between solid and solution due to continuous agitation. This results in a biased high test result. In particular for runoff, the water/rock contact time under ambient conditions will likely not be sufficiently long to attain equilibrium.

In addition, short-term leach tests are not capable of simulating transient behavior such as sulphide oxidation. Although the latter is not of concern for the Ambatovy/Analamay samples due to a general absence of reactive sulphides, limited consecutive SPLP testing conducted on behalf of Phelps Dodge identified concentration trends over time that were not captured by the single-stage testing which formed the basis for the derivation of input water qualities.

A third uncertainty is related to the small sample set. For the ferricrete and LMS, only one SPLP test was done, while for the ferralite the results from four SPLP tests were available. Due to this small sample set, compositional heterogeneity within the various lithologies is not accounted for.

3.2.3.2 Results

Geology

The mine will develop the Ambatovy and Analamay resource areas, containing an estimated 190 million tonnes of mineralized material which is approximately 1.1% nickel and 0.1% cobalt. About 60,000 tonnes of nickel and 5,000 tonnes of cobalt will be extracted annually for a period of at least 20 years. This will not

represent a negative impact on any existing resource users, as these geologic reserves are not being mined at present by local land users.

The removal of the geologic resources will limit the future capability for the development of the resource (as opposed to the no action alternative, in which the option will continue to exist for a mine at the site at a future date). However, in economic terms, assuming the geologic resource should be used, the most efficient use of the resource is at present, to maximize present economic value. Therefore, given that the development of the geologic resource will occur in an efficient manner, there are no negative effects of the project on geologic resources as compared to the no-action alternative.

Geochemistry

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 integral to the Water Quality Impact Analysis Section (Volume B, Section 3.9).

3.3 SOILS

3.3.1 Introduction and Study Area

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

The mine site study area for soils is the mine project footprint study area presented in Volume A, Figure 7.2-1. It includes the mine and water intake pipeline direct disturbance areas.

3.3.2 Baseline Summary

3.3.2.1 Regional Overview

Soils of the mine region have developed on old, geomorphically stable terrain with almost no vestige of the original rock structure. Intense weathering in the humid tropics from high temperatures, abundant moisture and time has resulted in deep soil development.

Tropical soils are generally low in nutrients due to the high rainfall which promotes weathering and leaching of minerals through the soil profile and out of the root zone. High soil temperatures and moisture conditions favour high levels of biological activity including organic matter production and its rapid degradation, which result in low organic matter. Nutrient holding capacity of soils in the humid tropics is mainly a function of humus content and is very low where humus content is low (Whitmore 1975). Roots are concentrated at the soil surface even though many tropical subsoils do not have any physical characteristic that would restrict rooting. Reclamation of vegetation in tropical soils is challenging because the soils are low in nutrients, notably nitrogen and phosphorus (Zonn 1986).

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

3.3.2.2 Mine Site Soils

Four major soil types were mapped from the field program and are summarized below.

Armoured ferricrete soils were observed on topographic plateaus with a hard, rock-like surface layer. These soils are classified as Entisols (Lithic Hapluumbrepts and Lithic Ustorthents) and Oxisols (Typic Acrhumox) under the United States Department of Agriculture (USDA) system.

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

Red/yellow ferrilitic soils were usually located in topographic lower slope positions. These soils have fewer concretions and were classified as Ultisols (Typic Paleudults) or as Oxisols (Oxic Dystropepts) under the USDA system.

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

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

3.3.3 Impact Assessment

3.3.3.1 Issue Scoping

The main potential issues relating to soils are:

- soil removal and disturbance;
- soil erosion
- loss of soil nutrients;
- soil compaction;
- soil contamination;
- loss of unique soils; and

- reclamation.

Many of these issues are inter-related. For example soil removal and disturbance is related to loss of unique soil and loss of soil nutrients.

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 mine activities and facilities with soil resources (Table 3.3-1). The interactions were rated to highlight the key issues and to help focus the assessment.

Table 3.3-1 Project Interaction Matrix

| Project Activities or Facilities | Soil ^(a) | Issue | Comments |
|--------------------------------------|---------------------|--|---|
| pre-construction phase | | | |
| exploratory drilling | L | increased short-term soil erosion risk on slopes >10% | short-term issue |
| Construction phase | | | |
| vegetation clearing | H | wind and water erosion; soil compaction from equipment | water erosion risk will be high until exposed areas revegetated |
| loss of ferricrete soils | H | dense soils on plateau creates unique vegetation growing conditions | permanent loss of soils as these conditions cannot be reclaimed |
| topsoil removal | L | wind and water erosion risk increases, loss of soil quality (nutrient loss, soil compaction) | very little topsoil on ferricrete soils |
| overburden removal | M to H | wind and water erosion; soil compaction from equipment | impact depends on length of time soil exposed |
| ore removal | N to L | wind and water erosion; soil compaction from equipment | impact depends on length of time soil exposed |
| potential spills | L to M | contamination from spills | impact depends on spill response |
| reclamation and closure phase | | | |
| removal of equipment | P | removal of potential 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.

Only those activities rated moderate or high were analyzed in detail in the assessment.

3.3.3.2 Key Question Evaluation

The key question for soils is:

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

A linkage diagram for potential impact pathways is provided in Volume H, Appendix 9.

Impact Pathways

Key Question ST-1 analyzes the effects associated with construction, operations and reclamation of the mine 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 mine include site clearing and surface disturbance to permit mine construction and operation. Area preparation for facility construction will involve removing the soil cover. Topsoil may not be salvaged for future reclamation operations on ferricrete soils. While the mine will be progressively reclaimed, methods for reclamation of vegetation on tropical soils are still in development.

Soil erosion is a process involving soil movement from one area to another by wind and water. Soil erosion can result in alteration or loss of soil quality, a process that can subsequently affect vegetation growth. The mine will result in vegetation removal, thereby exposing the soil and increasing the probability for erosion.

Soil compaction results in a reduction in porosity and an increase in soil bulk density. It is caused by external pressure resulting from construction-related equipment and vehicle traffic. The potential loss of soil structure from soil compaction can affect vegetation growth, especially root development, aeration and drainage. The mine will involve equipment traffic and activity on soils.

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. There is a potential for spills and leaks associated with the mine.

Ferricrete soils occur on the mine plateaus and create unique growing conditions for azonal vegetation. Since the dense surface horizon of ferricrete soils cannot be reproduced, the loss of unique soils will occur.

Tropical laterite soils are naturally low in nutrients and have a low pH which also creates potential metal toxicity problems for plant growth. Topsoil may not always be able to be salvaged before mining and stored for future use, so further loss of nutrients will occur.

Assessment Methods

The assessment methodology included an analysis of potential linkages between mine activities and soil resources, the analysis of effects identified by the Key Question and a classification of residual effects associated with the Key Question.

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

- The GIS quantified areas of soil types to be disturbed within the mine footprint.
- Impact ratings were determined based on the net permanent loss of unique soils (ferricrete) during the construction phase, the overall change in area of soils following reclamation and closure, and a qualitative assessment of potential changes in soil quality following reclamation and closure.

3.3.3.3 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 |

3.3.3.4 Mitigation

Soil Erosion

Soil erosion is the displacement of soil by wind or water action. Specifically the following features can affect soil loss (Wischmeier and Smith 1961, Gee et al. 1976):

$$A = f(R, K, L, S, C, P)$$

Where:

- A = erosion loss in tons per acre per year;
- R = rainfall factor;
- K = soil erodibility factor;
- L = slope-length factor;
- S = slope-gradient factor;
- C = vegetative cover and management factor; and
- P = practices used for erosion control.

Soil erodibility 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 mine area will have a high erosion potential due to the fine-textured surficial soils (Volume I, Appendix 2.1).

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 mine plan outlines that mine pit slopes will be greater than 30%, (Volume B, 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 topsoil where feasible (except ferricrete soils) 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 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 until a protective vegetative cover is established.
- 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). Other species can then be planted between the strips of Vetiver (Volume B, Section 6).

The following mitigations will be applied to prevent the siltation of watercourses:

- Prohibit the operation of construction equipment close to the banks of watercourses where there is a risk of bank sloughing, failure of the vehicle crossing or flooding of the work area.
- Excavate cross ditches to divert runoff away from watercourses.
- Construct berms containing overburden, timber, lumber, sandbags, rock, and/or straw bales on approach slopes and/or banks to divert runoff off the site and onto well-vegetated lands.
- Place sand bags strategically to help stabilize and add height to banks to prevent flooding of nearby areas especially where vegetation has been removed.

Loss of Soil Nutrients

Tropical soils are naturally very low in nutrients, with a low cation exchange capacity (CEC). Phosphorus deficiency is widespread in the tropics, due to P fixation, low total phosphorus reserves in organic matter and strong weathering (Juo and Franzluebbers 2003). Tropical soils contain high amounts of iron and aluminum oxides that react with soluble phosphate ions released during mineralization to form less soluble iron and aluminum phosphates (phosphorus fixation). Much of the phosphorus and other cations are derived from the organic soil fraction. Therefore, removal of the surface organic layer will reduce the availability of many minerals.

Organic matter content determines many factors of tropical soil fertility (Young 1976). This organic matter has developed over time, under equilibrium conditions, where the rate of input from decomposing plant material approximately equals plant uptake. With the depletion of plant litter sources combined with various processes (e.g., leaching, oxidation and mineralization), the nutrient availability of plant nutrients such as phosphorus diminishes. Losses of organic matter are also always accompanied by parallel losses in organic nitrogen which constitutes the dominant form of soil nitrogen. This form of nitrogen is not available in most tropical forest soils after long periods of disturbance.

Mitigations to restore soil nutrients in 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.
- As appropriate 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 mine area. It will be important to ensure that organic matter is reincorporated during reclamation since the organic matter has an important controlling function on soil fertility (see Volume B, Section 6).

Compaction

Soil compaction usually results from vehicular traffic passing over soil intended to support plant growth and has the following effects:

- decreased movement of water and air into and within the soil (Gupta and Allmaras 1989);
- decreased soil water storage capacity;
- decreased water infiltration and increased surface runoff and erosion;
- modified soil hydrology, groundwater recharge and increased risk of runoff and erosion;
- reduced plant root proliferation and penetration (Wolf and Hadas 1984); and
- decreased plant root penetration into the soil profile with resultant decreased availability of soil water and nutrients to plants.

Soil compaction has a significant effect on soil productivity and the ability of a site to support a productive sustainable vegetative community. Soil compaction issues can take years to alleviate.

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

- minimize the number of passes on an area once reclaimed;
- cultivate compacted soil before revegetation; and
- use deep-rooted vegetation to loosen the compaction.

Soil Contamination

General mitigation to prevent soil contamination will include the following:

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

3.3.3.5 Results

A total of 1,734 ha of soils will be disturbed by the mine over the life of the project (Table 3.3-3). The majority of disturbed soils will be red/yellow ferrilitic soils (731 ha, 42 % of total). The second most common disturbance type is the armoured ferricrete soils (474 ha, 27% of total). Ferricrete soils are associated with azonal vegetation and once disturbed the dense surface horizon cannot be reclaimed following mine closure. Therefore, there will be a permanent loss of 474 ha of these unique soils following mining (Table 3.3-3). However, other soils will form with the aid of reclamation amendments. When reclamation is completed following closure, there will be no overall net loss of soils due to the mine, although different soils will predominate.

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

| Soil Type | Area (ha) | Percent of LSA (%) |
|-----------------------|--------------|--------------------|
| armoured ferricrete | 474 | 27 |
| organic | 13 | 1 |
| pisolite | 516 | 30 |
| red/yellow ferrilitic | 731 | 42 |
| total | 1,734 | 100 |

3.3.3.6 Impact Analysis

Residual Impacts

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

Mine construction will result in a gradual disturbance of the mine pits as mining progresses. Once mine construction disturbs the dense surface horizons of ferricrete soils, these soils conditions will not be replicated following reclamation. Also, the erosion risk of all soils will increase substantially with the removal of vegetation. Due to the relatively short construction time period, the environmental consequence was rated as moderate.

During mine operation, the surface soil erosion risk will increase substantially due to the long length of time that soils will be without vegetation cover. While many mitigations will be implemented to control erosion (Section 3.3.3.4), the high intensity of precipitation in the area makes erosion events highly likely. The environmental consequence for soils is high during operations.

The environmental consequence was rated as low following closure since natural erosion rates are expected once a stable vegetation cover was established (see Volume B, Section 6). However, as noted above, ferricrete soils will not be reclaimed following mine closure.

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 Mine Have On Soils? | | | | | | | |
| construction | negative | high | local | short-term | no | low | moderate |
| operations | negative | high | local | medium-term | no | low | high |
| closure | negative | low | local | long-term | no | low | low |

3.3.3.7 Prediction Confidence

The soil impact classification relies heavily on the planned reclamation program to return a productive soil and implement successful erosion control methods. There are uncertainties regarding the reclamation of tropical soils and the success of erosion control during very high rain fall events. Planned reclamation research will address these issues (Volume B, Section 6).

3.3.3.8 Monitoring

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

- ensuring environmental protection measures are being followed during mine construction, operations and closure;
- ensuring overburden stockpile stability;
- measuring soil quality and vegetation performance; and
- documentation of the monitoring results.

3.3.4 Conclusions

Following mitigation, the mine will have a moderate environmental consequence for soils during the construction phase, a high environmental consequence during the operation phase and a low environmental consequence following closure and reclamation. The two main issues are the increase in erosion risk of the fine-textured soils once vegetation is cleared and the loss of the unique ferricrete soils. 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

3.4.1 Introduction

This section of the Ambatovy Project (the project) Environmental Assessment (EA) presents an air quality impact assessment of the mine as required by the Terms of Reference (ToR) from the Madagascar National Office for the Environment (ONE 2004). The information presented includes details on the following:

- air quality concerns identified by stakeholders and regulators;
- project activities that may affect air quality;
- mitigations incorporated in the project design for these impacts;
- the existing air quality in the study area;
- the dispersion model used for the assessment;
- impact assessment approach and results for key air quality issues; and
- monitoring recommendations and identified mitigations to reduce residual air quality impacts associated with the mine.

Potential air quality issues identified in the EA include:

- emissions from diesel-fired generators;
- emissions from mine fleet vehicles; and
- dust generated by mine vehicles.

The air quality assessment includes a comprehensive evaluation of the effects on atmospheric concentrations and deposition values that could result from emissions from all significant project sources. Although the air quality assessment is complete as a stand-alone evaluation, it also forms an integral part of the overall evaluation of the project, with information being supplied to biological and social disciplines.

The focus of the air assessment is to evaluate changes in the regional air quality and determine compliance with applicable regulations. The effects of air quality on environmental receptors such as human health, wildlife health, aquatic resources and terrestrial resources are addressed in the appropriate sections of Volume B.

3.4.2 Assessment Boundaries

3.4.2.1 Temporal Scope

Temporal considerations for the EA are based on the Ambatovy Project description and they vary among EA components because of the different ways the project components interact with the environment. The air assessment is based on consideration of the mine plan and the year in which the highest emissions are expected to occur. This approach results in a conservative impact assessment since the worst case emissions are expected for only one year. All other years in the life of the mine are expected to result in lower air predictions than those presented here.

3.4.2.2 Spatial Scope

The study area selected for the air quality assessment of the mine is 20 by 20 km in size, centred on the mine site, as illustrated in (Volume A, Section 7, Figure 7.2-1). Within the 400 km² study area is where the majority of the air quality effects associated with the mine are expected to occur. The study area has also been used when presenting the air quality predictions graphically.

One of the objectives of the air quality evaluation is to help address questions from regional stakeholders regarding the possible effects of the mine on the air quality in their communities. To facilitate this, air quality predictions were made for each of the community receptors indicated in Table 3.4-1.

3.4.3 Assessment Methodology

The air quality assessment of the mine made extensive use of an air dispersion model to evaluate potential air quality effects due to emissions from the mine. The steady-state (2-D) version of the CALPUFF dispersion model was determined to be the best model for assessing the air emissions from the mine. This modelling system has been reviewed extensively and is recommended for use by regulators in various jurisdictions. One advantage of CALPUFF is that it can account for the chemical transformations of emitted SO₂ and NO_x. Furthermore it can model wet and dry deposition.

Table 3.4-1 Community Locations Near Mine Site

| Community | Distance [km] | Direction |
|-------------------|---------------|-----------|
| Amboditrampanga | 6.9 | E |
| Ambodivato | 9.6 | SW |
| Ambodivoasary (1) | 9.2 | S |
| Ambodivoasary (2) | 12.3 | SE |
| Ambohibary | 11.3 | SW |
| Ambohimanarivo | 7.9 | WNW |
| Ampitambe | 8.4 | W |
| Analakely | 9.8 | ESE |
| Analalava | 10.9 | SW |
| Andranokoaka | 9.5 | W |
| Antanambao | 7.6 | W |
| Antaniditra | 7.6 | E |
| Antsahapandrano | 6.8 | ENE |
| Befotsy | 9.5 | WSW |
| Mahamanana | 8.6 | SSW |
| Mahatsara | 7.1 | W |
| Menalamba | 8.2 | ESE |
| Nangarana | 12.3 | NNE |
| Sahamalotra | 4.6 | ESE |
| Sakalava Ambony | 8.8 | N |

Note: Distance and direction relative to slurry processing area.

The dispersion modelling completed for the air quality assessment included the following key aspects:

- selection of dispersion modelling receptors;
- conversion of predicted NO_x concentrations to NO₂ concentrations using the Ozone Limited Method (OLM); and
- use of two years of meteorological data from the on-site meteorological station located at the mine exploration camp.

A detailed description of the air dispersion modelling methodology is presented in Volume I, Appendix 4.2.

3.4.3.1 Assessment Criteria

Madagascar does not have ambient air quality criteria; therefore, World Bank and World Health Organization (WHO) guidelines were used. The World Bank provides guidelines for SO₂, NO₂ and PM₁₀ specifically for open pit mining and

milling industries (World Bank 1995). The World Bank also provides recommendations for certain pollutant thresholds (i.e., SO₂, NO₂, PM₁₀ and Total Suspended Particulate [TSP]) when specific country or project guidelines are not available. The thresholds used for defining a moderately degraded airshed were used as the TSP criteria. In the absence of World Bank guidelines, the WHO guidelines were used (i.e., lead and mercury). Table 3.4-2 summarizes the air quality criteria used for the mine.

Table 3.4-2 Ambient Air Quality Criteria

| Parameter | World Bank ^(a) | | WHO ^(c) | Criteria Used for Project |
|--------------------------------------|---------------------------|--|--------------------|---------------------------|
| | Open Pit Mining | Moderately Degraded Airshed ^(b) | | |
| Sulphur Dioxide (SO ₂) | | | | |
| 24-hour average [µg/m ³] | 500 | 150 | 125 | 500 |
| annual average [µg/m ³] | 100 | 80 | 50 | 100 |
| Nitrogen Dioxide (NO ₂) | | | | |
| 24-hour average [µg/m ³] | 200 | 150 | — | 200 |
| annual average [µg/m ³] | 100 | 100 | 40 | 100 |
| Total Suspended Particulate (TSP) | | | | |
| annual average [µg/m ³] | — | 80 | — | 80 |
| PM ₁₀ | | | | |
| 24-hour average [µg/m ³] | 500 | 150 | — ^(d) | 500 |
| annual average [µg/m ³] | 100 | 50 | — ^(d) | 100 |
| Lead | | | | |
| annual [µg/m ³] | — | — | 0.5 | 0.5 |
| Mercury | | | | |
| annual [µg/m ³] | — | — | 1 | 1 |

^(a) Source: World Bank 1995, 1998.

^(b) These values are based on pollutant-specific recommendations from the World Bank when country guidelines are not available.

^(c) Source: WHO 2000.

^(d) WHO recommends a risk-based approach for assessing the effects of PM₁₀, therefore no guidelines are provided.

“—” Indicates no criteria available.

The impact assessment methodology used for the Ambatovy Project has been described in detail in Volume A, Section 7 and involves the evaluation of residual effects. The residual effects for air were classified using quantification criteria to determine environmental consequence. Each impact is first described in terms of the following criteria: magnitude, geographic extent and duration. Two additional criteria were also used for the air quality assessment: reversibility and frequency. Table 3.4-3 details the Impact Description Criteria for the air quality component of the EA.

Table 3.4-3 Impact Description Criteria for Air Quality

| Resource | Direction | Magnitude | Geographic Extent | Duration | Reversibility | Frequency |
|-------------|---|---|---|--|--|---|
| Air Quality | positive: a decrease in emissions and/or ambient concentrations negative: an increase in emissions and/or ambient concentrations | magnitude varies with the air contaminant being evaluated; specifics provided in Table 3.4.4. | local: effect restricted to the LSA regional: effect extends beyond the LSA 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 |

Direction of an impact may be positive or negative with respect to the key question (e.g., a reduction in predicted air concentrations would be considered as positive, whereas an increase in air concentrations would be considered negative).

Magnitude is a measure of the degree of change in a measurement or analysis endpoint, and is classified as negligible, low, moderate or high. The categorization of the impact magnitude was based on a set of criteria, ecological concepts and professional judgment.

The air quality resources evaluated and the magnitude criteria used to evaluate the residual effects are outlined in Table 3.4-4. Generally, the magnitude would be classified as “negligible” if there was no increase predicted to result from the mine emissions. A “low” magnitude would be assigned when an increase was predicted, however the maximum value remains below 5% of the criteria. A “moderate” magnitude would be assigned when the maximum concentrations are below the criteria but above 5% of the criteria. A “high” magnitude would be assigned when the maximums are greater than the criteria. In some cases, applicable World Bank guidelines were not available. In these cases, WHO criteria were substituted.

Reversibility indicates the potential for recovery of the ecological end point. An effect is defined as not reversible if the resource element cannot be restored to pre-impact condition within the long-term (as defined under duration in Volume A, Section 7). The impact on air quality is always reversible.

Frequency describes how often the effect occurs within a given time period and is classified as low, medium or high in occurrence.

Table 3.4-4 Magnitude Classifications for Air Quality

| Parameter | Magnitude ^(a) | | | |
|---|--------------------------|---------|----------|-------|
| | Negligible | Low | Moderate | High |
| 24-hour SO ₂ concentration [µg/m ³] | no increase | ≤ 25 | ≤ 500 | > 500 |
| annual SO ₂ concentration [µg/m ³] | no increase | ≤ 5 | ≤ 100 | > 100 |
| 24-hour NO ₂ concentration [µg/m ³] | no increase | ≤ 10 | ≤ 200 | > 200 |
| annual NO ₂ concentration [µg/m ³] | no increase | ≤ 5 | ≤ 100 | > 100 |
| annual TSP concentration [µg/m ³] | no increase | ≤ 4 | ≤ 80 | > 80 |
| 24-hour PM ₁₀ concentration [µg/m ³] | no increase | ≤ 25 | ≤ 500 | > 500 |
| annual PM ₁₀ concentration [µg/m ³] | no increase | ≤ 5 | ≤ 100 | > 100 |
| annual lead concentration [µg/m ³] | no increase | ≤ 0.025 | ≤ 0.5 | > 0.5 |
| annual mercury concentration [µg/m ³] | no increase | ≤ 0.05 | ≤ 1 | > 1 |

^(a) The magnitude is based on the maximum prediction values outside the property boundary.

Table 3.4-5 shows the screening system for determining environmental consequence. This screening system is based on the fact that the geographic extent of the air quality impacts are local, direction is negative, the duration is medium-term (3 to 30 years) and the impacts are reversible.

Table 3.4-5 Air Quality Screening System of Environmental Consequences

| Magnitude | Frequency | Environmental Consequence |
|------------|-----------|---------------------------|
| negligible | all | negligible |
| low | low | low |
| low | moderate | low |
| low | high | low |
| moderate | low | low |
| moderate | moderate | low |
| moderate | high | low |
| high | low | moderate |
| high | moderate | moderate |
| high | high | moderate |

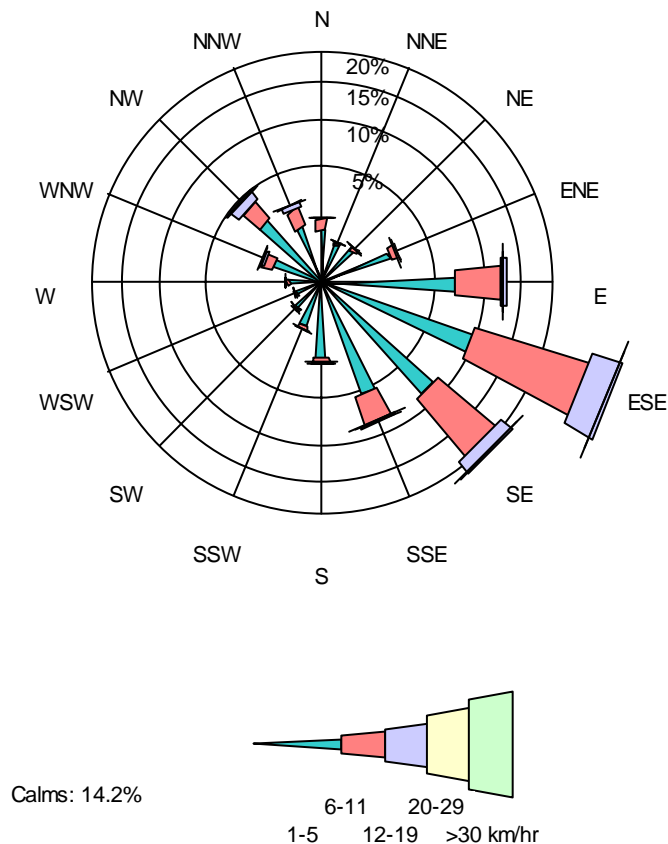
Note: Screening system based on the fact that the geographic extent is local, direction is negative and the impacts are reversible.

3.4.4 Baseline Summary

Based on data from 1997 to 2004, hourly temperatures at the exploration camp ranged from 7.6°C to 31.1°C with an annual average temperature of 17°C. Annual average rainfall at the mine site was about 1,400 mm with almost 70% occurring from December to March.

Figure 3.4-1 shows a windrose of data collected at the exploration camp from 1997 to 2004. The windrose consists of bars whose length indicates the frequency of winds blowing from a given direction. The bars are also broken into sections, each of which defines a speed range. A longer section indicates that winds blow more frequently at a given speed for that direction. East-southeast and southeast winds were predominant and occur 59% of the time excluding calms. The average annual wind speed was 6 km/hr with maximum hourly speeds of up to 48 km/hr and gust speeds over 80 km/hr. There was also a high frequency of calm conditions (14.2%).

Figure 3.4-1 Observed Winds at Mine Exploration Camp



A baseline ambient air quality study was not performed for the EA; however, ambient air quality was expected to be good based on the lack of industrial activity in the region of the mine site. The exception could be airborne particles resulting from fires, road dust generated during the dry season or from agricultural activities.

In a study done on the southern coast of Madagascar in August 2000, air quality was monitored at eight locations in and near Fort Dauphin. Results showed very low concentrations of sulphur dioxide (SO₂), oxides of nitrogen (NO_x), particulates as PM₁₀ (particulate less than 10 µm in diameter) and carbon monoxide (CO). All eight locations were classified as pristine (less than 20% of the reference standard) or clean (20 to 39% of the reference standard) (SENES 2001). The rural stations in this study, which were all classified as pristine, are considered representative of the ambient air quality at the mine site.

3.4.5 Impact Assessment

3.4.5.1 Issue Scoping

Through consultation with stakeholders (Volume A, Section 6) and review of previous environmental assessments for resource developments in Madagascar and elsewhere, specific air quality issues were identified. The following three main factors could affect air quality in the mine study area:

- mine fleet exhaust;
- dust; and
- emissions from the ore processing facilities.

The key indicators are sulphur dioxide (SO₂), oxides of nitrogen (NO_x), nitrogen dioxide (NO₂), total suspended particulates (TSP), particulate matter with diameter less than 10 µm (PM₁₀), trace metals and greenhouse gases.

The key questions addressed below for air quality are:

| | |
|--------------------------|---|
| Key Question AQ-1 | How Will The Development of the Mine Affect Air Quality? |
| Key Question AQ-2 | How Will The Development of the Mine Affect the Production And Management of Greenhouse Gases? |

3.4.5.2 Key Question AQ-1 How Will The Development of the Mine Affect Air Quality?

Most air effects are expected to occur during the construction and operation phases of the project as shown in the linkage diagrams for air quality (Volume H, Appendix 9). Changes in air quality may have an effect on vegetation, aquatic resources, wildlife health and/or human health. Greenhouse gas emissions may also change due to the project.

Mine Emissions

The activities at the mine will result in the release of emissions of SO₂, NO_x and particulate matter to the atmosphere. Emission estimates were based on established emission factors, supplier specification data and mass balances. Where information on equipment or processes was unavailable, conservative assumptions were made to fill in data gaps.

Emissions sources at the mine include power generation, mine fleet emissions, road dust, and fugitive dust resulting from activities such as bulldozing, drilling, grading, and loading and unloading of materials.

Emission estimates were developed based on maximum diesel fuel consumption, mine fleet size, and material handled quantities. This scenario would result in the maximum emissions and predicted ground-level concentrations.

The effect of mitigations to be employed at the mine was incorporated in the emission estimates. For example, emissions were estimated assuming a high level of mitigation on dust emissions related to vehicle traffic. The proponent will implement a dust mitigation program at the mine to ensure dust levels from road traffic are kept to a minimum at all times.

During periods with high wind speeds, it is possible for dust to be eroded from exposed areas of the mine, specifically stockpiles. While the emissions due to these events can be calculated, it is not usually possible to accurately model the releases. However, the CALPUFF dispersion model allows the user to input a threshold wind velocity, below which the emissions of wind-blown dust will not occur. In assessing the particulate releases from the mine stockpiles, it was determined that wind erosion of the exposed areas would occur when the wind speeds exceeded 10 m/s. Such wind speeds were observed to occur at the mine only 20 hours during the year. These high wind speeds usually only occur during the rainy season, when there would be no issues with dust anyway. Therefore, wind-blown dust from the mine was not included in the air quality assessment.

Table 3.4-6 presents a summary of the estimated emissions from the mine.

Table 3.4-6 Mine Air Emissions Summary^(b)

| Source | Emission Rate [t/d] | | | |
|----------------------------|---------------------|-----------------|------------------|-------------|
| | SO ₂ | NO _x | PM ₁₀ | TSP |
| diesel generators | 0.35 | 2.37 | 0.06 | 0.07 |
| mine fleet | 0.42 | 1.59 | 0.06 | 0.06 |
| road dust | 0.00 | 0.00 | 0.21 | 0.70 |
| fugitive dust | 0.00 | 0.00 | 0.06 | 0.22 |
| total^(a) | 0.77 | 3.96 | 0.39 | 1.06 |

^(a) Some numbers are rounded for presentation purposes. Therefore, it may appear that the totals do not equal the sum of the individual values.

^(b) Based on data provided in volume I, Appendix 4.2.

Note: Trace metals are scaled off of particulate predictions based on metal content of ore and diesel fuel; therefore, emissions are not presented.

Mitigation

The air quality assessment of the mine is based on the mining year with the highest fuel consumption. The proponent has committed to using Tier 2 mine fleet vehicles which have lower NO_x emissions. The U.S. Government and engine manufacturers have worked together to develop a four-tiered system for regulating emissions of NO_x, particulates, carbon monoxide and total hydrocarbons from diesel engines. Since 1996 and the beginning of the implementation of Tier 1 emission standards, consistently more stringent regulations will be implemented in stages. The Tier 2 standards come into effect for off-road diesel engines greater than 750 hp in 2006. The proponent has also committed to reducing dust generated by vehicle traffic by watering roads.

Results

Key Compounds

The expected emissions of SO₂, NO_x, TSP, PM₁₀ and trace compounds from the mine were input into the CALPUFF dispersion model to determine ground-level concentrations across the study area and at selected regional communities. The CALPUFF model was run in the steady-state (2-D) mode using two years of meteorological observations from the on-site meteorological station. A summary of the modelling results are presented in Table 3.4-7. The results are also shown graphically in Volume I, Appendix 4.2.

The annual TSP predictions are slightly below the World Bank criteria of 80 µg/m³. These predictions are likely conservative since the roads on-site will

have a thick layer of ferricrete which will reduce dust generation. Also, the proponent will mitigate dust generation by watering on-site roads.

Table 3.4-7 Summary of Air Quality Predictions in the Mine Study Area

| Parameter | Averaging Period | |
|---|------------------|------------|
| | 24-Hour | Annual |
| Sulphur Dioxide (SO₂) | | |
| maximum SO ₂ concentration [µg/m ³] | 258.3 | 152.0 |
| maximum SO ₂ concentration outside mine buffer [µg/m ³] | 111.2 | 52.3 |
| distance to maximum concentration [km] ^(a) | 5.2 | 5.2 |
| direction to maximum concentration ^(a) | NNE | NNE |
| World Bank Open Pit Mining SO₂ Criteria [µg/m³] | 500 | 100 |
| Nitrogen Dioxide (NO₂) | | |
| maximum NO _x concentration [µg/m ³] | 1,144.2 | 577.6 |
| maximum NO ₂ concentration [µg/m ³] | 165.2 | 117.9 |
| maximum NO ₂ concentration outside mine buffer [µg/m ³] | 126.9 | 85.9 |
| distance to maximum concentration [km] ^(a) | 1.0 | 1.0 |
| direction to maximum concentration ^(a) | WNW | WNW |
| World Bank Open Pit Mining NO₂ Criteria [µg/m³] | 200 | 100 |
| Total Suspended Particulate (TSP) | | |
| maximum TSP concentration [µg/m ³] | — | 220.9 |
| maximum TSP concentration outside mine buffer [µg/m ³] | — | 79.4 |
| distance to maximum concentration [km] ^(a) | — | 2.9 |
| direction to maximum concentration ^(a) | — | N |
| World Bank TSP Criteria [µg/m³] | — | 80 |
| Particulate Matter (PM₁₀) | | |
| maximum PM ₁₀ concentration [µg/m ³] | 127.9 | 78.9 |
| maximum PM ₁₀ concentration outside mine buffer [µg/m ³] | 53.0 | 28.0 |
| distance to maximum concentration [km] ^(a) | 2.9 | 2.9 |
| direction to maximum concentration ^(a) | N | N |
| World Bank Open Pit Mining PM₁₀ Criteria [µg/m³] | 500 | 100 |

^(a) Distance and direction are from the slurry processing area to the maximum concentration outside the mine buffer.

Tables 3.4-8 to 3.4-10 show the maximum predicted 24-hour and annual SO₂, NO₂, TSP and PM₁₀ concentrations at the communities due to emissions from the mine. Background concentrations due to community activities have not been added to the predictions due to lack of existing ambient air quality information. None of the concentrations exceed the World Bank criteria. Annual concentrations of lead and mercury were also predicted at communities and all values were well below the WHO annual criteria of 0.5 and 1 µg/m³, respectively. The results are shown in Volume I, Appendix 4.2, Section 3.4.4.

Table 3.4-8 Maximum Predicted SO₂ Concentrations in Communities

| Community | Maximum SO ₂ [µg/m ³] | |
|--|--|------------|
| | 24-hour | Annual |
| Amboditrampanga | 1.1 | 0.1 |
| Ambodivato | 0.6 | 0.1 |
| Ambodivoasary (1) | 1.6 | 0.1 |
| Ambodivoasary (2) | 0.4 | 0.0 |
| Ambohibary | 0.5 | 0.1 |
| Ambohimanarivo | 1.6 | 0.7 |
| Ampitambe | 0.9 | 0.2 |
| Analakely | 0.6 | 0.1 |
| Analalava | 0.5 | 0.1 |
| Andranokoaka | 1.0 | 0.2 |
| Antanambao | 1.9 | 0.4 |
| Antaniditra | 1.0 | 0.1 |
| Antsahapandrano | 5.7 | 1.7 |
| Befotsy | 0.6 | 0.1 |
| Mahamanana | 1.6 | 0.5 |
| Mahatsara | 1.9 | 0.4 |
| Menalamba | 0.9 | 0.1 |
| Nangarana | 1.3 | 0.4 |
| Sahamalotra | 1.6 | 0.2 |
| Sakalava Ambony | 5.9 | 2.6 |
| World Bank Open Pit Mining SO₂ Criteria [µg/m³] | 500 | 100 |

Note: Predicted community concentrations do not include background values.

Table 3.4-9 Maximum Predicted NO₂ Concentrations in Communities

| Community | Maximum NO ₂ [µg/m ³] | |
|--|--|------------|
| | 24-hour | Annual |
| Amboditrampanga | 4.1 | 0.4 |
| Ambodivato | 2.2 | 0.4 |
| Ambodivoasary (1) | 8.1 | 0.4 |
| Ambodivoasary (2) | 1.5 | 0.2 |
| Ambohibary | 1.7 | 0.3 |
| Ambohimanarivo | 10.4 | 3.9 |
| Ampitambe | 4.9 | 0.8 |
| Analakely | 2.3 | 0.3 |
| Analalava | 1.7 | 0.3 |
| Andranokoaka | 5.6 | 1.1 |
| Antanambao | 9.4 | 1.8 |
| Antaniditra | 4.2 | 0.5 |
| Antsahapandrano | 23.9 | 6.6 |
| Befotsy | 2.1 | 0.4 |
| Mahamanana | 7.1 | 1.9 |
| Mahatsara | 9.4 | 1.8 |
| Menalamba | 3.6 | 0.5 |
| Nangarana | 5.6 | 1.5 |
| Sahamalotra | 7.0 | 1.0 |
| Sakalava Ambony | 26.5 | 10.2 |
| World Bank Open Pit Mining NO₂ Criteria [µg/m³] | 200 | 100 |

Note: Predicted community concentrations do not include background values.

Table 3.4-10 Maximum Predicted Particulate Concentrations in Communities

| Community | Maximum TSP Concentration [µg/m³] | Maximum PM ₁₀ Concentration [µg/m³] | |
|------------------------------------|-----------------------------------|--|------------|
| | Annual | 24-Hour | Annual |
| Amboditrampanga | 0.0 | 0.4 | 0.0 |
| Ambodivato | 0.0 | 0.1 | 0.0 |
| Ambodivoasary (1) | 0.0 | 0.6 | 0.0 |
| Ambodivoasary (2) | 0.0 | 0.4 | 0.0 |
| Ambohibary | 0.0 | 0.1 | 0.0 |
| Ambohimanarivo | 0.2 | 0.6 | 0.2 |
| Ampitambe | 0.0 | 0.3 | 0.0 |
| Analakely | 0.0 | 0.5 | 0.0 |
| Analalava | 0.0 | 0.1 | 0.0 |
| Andranokoaka | 0.0 | 0.3 | 0.1 |
| Antanambao | 0.1 | 0.4 | 0.1 |
| Antaniditra | 0.0 | 0.6 | 0.0 |
| Antsahapandrano | 0.0 | 0.8 | 0.1 |
| Befotsy | 0.0 | 0.1 | 0.0 |
| Mahamanana | 0.0 | 0.4 | 0.0 |
| Mahatsara | 0.0 | 0.5 | 0.1 |
| Menalamba | 0.0 | 0.7 | 0.0 |
| Nangarana | 0.0 | 0.7 | 0.0 |
| Sahamalotra | 0.1 | 0.9 | 0.1 |
| Sakalava Ambony | 0.4 | 1.8 | 0.3 |
| World Bank Criteria [µg/m³] | 80 | 500 | 100 |

Note: Predicted community concentrations do not include background values.

Acidification

The preferred method for evaluating acid deposition is to determine Potential Acid Input (PAI), which takes into account the acidifying effect of the sulphur and nitrogen species. A detailed description of PAI is presented in Volume I, Appendix 4.2. The SO₂ and NO_x emissions were input into the CALPUFF dispersion model and PAI values predicted. The maximum annual PAI value predicted outside the mine buffer was 3.5 keq/ha/yr, which is located 1 km west-northwest of the slurry processing area. The PAI predictions are shown graphically in Appendix 4.2, Figure 4.2-12. The average PAI over the study area is 0.1 keq/ha/yr. The PAI values predicted for the mine are lower than those predicted for the process plant (see Volume D, Section 3.3.5.2). The effects of PAI on various ecosystems are discussed in appropriate biological sections of Volume B.

Odour

There will be no odourous compounds emitted from the mine; therefore, odour was not assessed for the mine.

Residual Impacts

Impact Classification

Emissions of SO₂, NO_x, particulates and trace compounds from the mine will result in changes to the ambient air quality. The magnitude of all of the changes is considered to be low (Table 3.4-11). The predicted concentrations of SO₂, NO₂, TSP, PM₁₀ and trace compounds were all within World Bank guidelines within the study area and at regional communities. These predictions result in low or moderate magnitude ratings for all of the evaluated parameters. Of the 16 parameters evaluated, all were rated as having a low environmental consequence.

Table 3.4-11 Residual Impact Classification for Effects to Air Quality

| Parameter | Direction | Magnitude | Geographic Extent | Duration | Reversibility | Frequency | Environmental Consequence |
|------------------------------------|-----------|-----------|-------------------|-------------|---------------|-----------|---------------------------|
| 24-hour SO ₂ | negative | moderate | local | medium-term | reversible | moderate | low |
| annual SO ₂ | negative | moderate | local | medium-term | reversible | high | low |
| community 24-hour SO ₂ | negative | moderate | local | medium-term | reversible | moderate | low |
| community annual SO ₂ | negative | moderate | local | medium-term | reversible | high | low |
| 24-hour NO ₂ | negative | moderate | local | medium-term | reversible | high | low |
| annual NO ₂ | negative | moderate | local | medium-term | reversible | moderate | low |
| community 24-hour NO ₂ | negative | moderate | local | medium-term | reversible | high | low |
| community annual NO ₂ | negative | low | local | medium-term | reversible | moderate | low |
| annual TSP | negative | low | local | medium-term | reversible | high | low |
| community annual TSP | negative | moderate | local | medium-term | reversible | moderate | low |
| 24-hour PM ₁₀ | negative | moderate | local | medium-term | reversible | high | low |
| annual PM ₁₀ | negative | low | local | medium-term | reversible | high | low |
| community 24-hour PM ₁₀ | negative | low | local | medium-term | reversible | moderate | low |
| community annual PM ₁₀ | negative | low | local | medium-term | reversible | high | low |
| community annual lead | negative | low | local | medium-term | reversible | high | low |
| community annual mercury | negative | low | local | medium-term | reversible | high | low |

Scientific Uncertainty

The evaluation of changes in air quality depends primarily on the use of air dispersion models to predict the ambient levels expected in the future. As with any form of prediction, there are uncertainties regarding the model's capability to predict concentrations accurately. To minimize some of these uncertainties, an accepted dispersion model (i.e., CALPUFF) was selected for the analysis. This model has been reviewed extensively in the United States to ensure that it provides realistic, but conservative, predictions.

The other uncertainty associated with the air quality predictions is tied to the predicted emissions from the mine. Possible uncertainty associated with the predicted emissions was limited by using established emission factors and the latest project description. Where uncertainties could not be avoided, conservative emission estimates were used to ensure that possible impacts were not underestimated.

Monitoring and Follow-Up

Based on the modelling and assessment results from the mine, no additional monitoring is recommended. Maximum predicted levels of SO₂, NO₂, particulates, lead and mercury all comply with the World Bank or WHO guidelines.

3.4.5.3 Key Question AQ-2 How Will The Development of the Mine Affect the Production and Management of Greenhouse Gases?

The linkage diagram for Key Question AQ-2 is provided in Volume H, Appendix 9.

Impact Analysis

The first step in completing the impact analysis for this key question is to characterize the greenhouse gas releases from the mine. Emissions of carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O) and total greenhouse gases (expressed as equivalent carbon dioxide [ECO₂], which includes the higher greenhouse potential of CH₄ and N₂O) were estimated for the operations phase of the mine.

Table 3.4-12 presents the estimated greenhouse gas (GHG) emissions during the operations phase of the mine. Estimated GHG emissions during operations are estimated to be 79 kt ECO₂/year.

Table 3.4-12 Summary of Greenhouse Gas Emissions from the Mine

| Source | Annual Greenhouse Gas (GHG) Emissions [kt/yr] | | | |
|----------------------------|---|-----------------|------------------|------------------|
| | CO ₂ | CH ₄ | N ₂ O | ECO ₂ |
| diesel generators | 41.35 | 0.00 | 0.00 | 41.49 |
| mine fleet | 37.83 | 0.00 | 0.00 | 37.98 |
| total^(a) | 79.18 | 0.00 | 0.00 | 79.47 |

^(a) Some numbers are rounded for presentation purposes. Therefore, it may appear that the totals do not equal the sum of the individual values.

Table 3.4-13 provides a summary of Madagascar national GHG emissions based on 1994 information. A comparison to the emissions from the mine (79 kt ECO₂/yr), helps to put the project into perspective. The national GHG emissions in 1994 were estimated to be 456,323 kt ECO₂/yr (MEEF 2004). The emissions from the mine would represent a 0.02% increase in national GHG emissions.

Table 3.4-13 Madagascar National Greenhouse Gas Emissions

| Greenhouse Gas Source | CO ₂ | | CH ₄ | N ₂ O |
|--|------------------------------|-----------------------------|-----------------|------------------|
| | Emissions <i>Emission</i> | Collected <i>Captage</i> | | |
| Total Emissions (kt/yr) <i>Emission totale nationale</i> | 432,429 | 671,451 | 426 | 42 |
| Total Emissions (kt ECO ₂ /yr) <i>Emission nationale en equivalent CO₂</i> | 432,429 | 671,451 | 10,444 | 13,450 |
| I Energy Sector <i>I Secteur Energie</i> | 1,141 | 0 | 33 | 0 |
| II Industrial Processes Sector <i>II Secteur Procèdes Industriels</i> | 5 | — | 0 | 0 |
| III Agriculture Sector <i>III Secteur Agriculture</i> | 0 | — | 327 | 42 |
| IV Land Use Change Sector <i>IV Secteur Changement D'Affectation</i> | 431,283 | 671,451 | 57 | 0 |
| V Waste Management Sector <i>V Secteur Gestion des Dechets</i> | — | — | 10 | — |
| Additional Information | | | | |
| A CO ₂ Emissions resulting from biomass <i>A Emission de CO₂ Issue de Biomasses</i> | 10,812 | | | |
| B Sequestration Balance <i>B Bilan de Sequestration</i> | -239,022 | | | |

Source: Le Ministre de l'Environnement des Eaux et des Forets, 2004.

“—” Indicates no emissions from this source.

3.4.6 Conclusions

The potential for emissions from the mine to affect the quality of air in the region is an issue for regional stakeholders. Despite the mitigation and control techniques incorporated in the operations of the mine, there will be an increase in the atmospheric emissions in the region due to the mine. The air quality assessment of the mine included predictions of SO₂, NO₂, TSP, PM₁₀, lead and mercury concentrations.

The key findings of the air quality assessment are as follows:

- The maximum predicted concentrations are below applicable World Bank Open Pit Mining or WHO criteria.
- All of the predicted concentrations in the regional communities meet the World Bank Open Pit Mining or WHO criteria.
- Based on estimated SO₂ and NO₂ emission rates, acid deposition rates were predicted to be less than 4 keq/ha/yr outside the mine buffer, with an average of 0.1 keq/ha/yr over the study area.
- The emissions from the mine (79 kt ECO₂ per year) would represent a 0.02% increase in national GHG emissions.

Of the 16 ambient air quality parameters assessed, all were rated as having a low environmental consequence.

3.5 NOISE

3.5.1 Introduction

The noise assessment of the Ambatovy Project (the project) provides a complete impact analysis of the proposed project and identifies the potential effects of sound emissions associated with the proposed project activities. In this volume of the Environmental Assessment (EA), project activities associated with the mine are assessed. Information is provided on existing noise levels in the area as well as the changes expected to result from the mine.

The focus of the noise assessment is on determining changes to the existing ambient noise levels due to project operations and comparing the results with noise guidelines from the World Bank. The assessment is conducted from the point of view of human response. The effects of noise on wildlife are assessed in Volume B, Section 4.2. Noise is also an input to the analysis of social effects in Volume B, Section 5.1.

A few key concepts relating to noise are presented below:

- “Sound” or “sound emissions” refers to the acoustic energy emitted by natural or man-made sources, including the project activities.
- “Noise” or “noise levels” refer to the levels that can be heard by a person or measured at a receptor.
- A noise “receptor” is a location where measurements or predictions of noise levels are made.
- The “volume” of a sound or noise is expressed on a logarithmic scale, in units called decibels (dB). Since the scale is logarithmic, a sound or noise that is twice as loud as another will only be three decibels (3 dB) higher. A 3 dB change is also the threshold at which a person may be able to notice a change in volume.
- Sound emissions and noise levels also have a “frequency”. The human ear does not respond to all frequencies in the same way. Mid-range frequencies are most readily detected by the human ear, whereas low and high frequencies are harder to hear. Environmental noise levels are usually presented as “A-weighted” decibels (or dBA), which incorporates the frequency response of the human ear. While low frequency noise may not be “heard”, it can often be felt.
- Outdoor noise is usually expressed as an “equivalent noise level” (L_{eq}), which is a logarithmic average of the measured or predicted noise levels over a given period of time. This is the preferred noise indicator for

environmental noise as it takes into account the natural variability of sound.

3.5.2 Study Areas

The study area used to assess noise from the mine encompasses a 10 km by 11 km area roughly centred on the mine footprint as illustrated in Volume A, Section 7.2. The following specific receptors within this area were selected as the basis for conducting the impact assessment:

- Behontsa
- Berano
- Sahamalotra

These were determined to be the primary village areas within the study area, based on the results of the socioeconomic surveys.

3.5.3 Baseline Summary

3.5.3.1 Introduction

A baseline noise study was completed for the project to establish existing noise levels at the proposed development areas as well as to provide information for the noise impact assessment. Establishing existing noise levels was also necessary in order to use the World Bank noise criteria.

3.5.3.2 Methods

Since Madagascar does not have established guidelines or regulations concerning noise measurements, the study was performed to meet the requirements of the World Bank. The World Bank requires noise be assessed at receptors that lie outside the project boundary based on the following time periods:

- daytime hours (7:00 AM to 10:00 PM)
- nighttime hours (10:00 PM to 7:00 AM) (WB, 1998)

One, 24-hour survey was done at each selected monitoring location to represent existing noise levels at community receptors around the mine. Surveys of this type and duration provide information on daily variability in noise levels. The sound level meter used recorded average (L_{eq}) and maximum (L_{max}) sound pressure levels once per minute during the monitoring period.

Weather data was measured at monitoring locations during each 24-hour survey period. Noise measurements are most accurate during weather conditions conducive to low relative humidity, warm temperatures (below 35°C), low winds and no cloud cover. Weather information was recorded throughout the monitoring period and action taken where necessary to ensure conditions remained optimal during noise measurement.

Two locations near the mine site were selected for conducting the noise survey: Behontsa and Berano. These locations were considered representative of the community noise receptors near the mine.

Detailed information regarding noise monitoring location selection and monitoring methods are provided in Volume I, Appendix 5.1.

3.5.3.3 Summary of Results

A summary of existing noise levels at assessment receptors is provided in Table 3.5-1.

Table 3.5-1 Summary of Existing Noise Levels, Ambatovy Project Mine Site

| Location | Period | Quietest Hour L _{eq} [dBA] | Period L _{eq} [dBA] |
|----------------------------|--------|--|---------------------------------|
| Behontsa ^(a) | day | 37 | 42 |
| | night | 33 | 34 |
| Berano ^(a) | day | 23 | 41 |
| | night | 20 | 40 |
| Sahamalotra ^(b) | day | 23 | 41 |
| | night | 20 | 40 |

^(a) Values taken from baseline measurements.

^(b) Baseline measurements from the Berano monitoring location were assumed for this receptor.

Detailed noise measurements including tables of hourly noise levels and graphs of one-minute raw data are provided in Volume I, Appendix 5.1.

3.5.4 Impact Assessment

3.5.4.1 Issue Scoping

Through consultation with stakeholders and review of previous environmental assessments for resource developments in Madagascar and elsewhere, several

issues were identified with respect to the potential impacts of the project on noise. Mine site factors that may affect noise levels include:

- noise generated by mining activities including blasting, transport of ore, crushing of ore, transport of waste rock and preliminary processing; and
- increased traffic on the access road, particularly during the construction phase, but also during operations may lead to localized increases in noise levels.

Both the construction and operation phases of the project are accounted for. Changes in noise due to the project may have an effect on wildlife and human health. This results in one key question for noise:

Key Question N-1 What Effect Will Noise From the Ambatovy Mine Activity Have on Sensitive Receptors?

An analysis of factors that may affect noise is shown as a linkage diagram in Volume H, Appendix 9.

3.5.4.2 Assessment Methods

The key indicator which will be used to assess potential changes in noise levels is the equivalent sound level or L_{eq} .

The assessment of changes in noise levels was accomplished by:

- determining potential receptors of noise;
- establishing baseline noise levels at those receptors;
- determining the amount of sound to be generated by project activity;
- predicting the amount of project-related noise that would be experienced at the identified receptors; and
- comparing predicted noise levels with baseline noise levels and applicable noise criteria.

Activities or equipment that have sound emissions were determined based on information contained in the Project Description and client-supplied equipment lists. Sound emissions for the various sources were based on noise measurements from similar equipment, manufacturer data or standard sound emission formulae.

Noise predictions were conducted using the Computer Aided Noise Abatement Model (CadnaA). The model was used to estimate the noise levels received at neighbouring communities due to sound emitted from the mine as well as predict noise levels surrounding the mine site. CadnaA is a three-dimensional noise prediction tool that calculates attenuation of noise including effects from the atmosphere, barriers, ground conditions, foliage and terrain. The model methods are consistent with International Standardization Organization (ISO) acoustic standards and World Bank criteria, providing L_{eq} noise levels over selected time periods.

The effects of noise on wildlife are assessed as part of the fauna impact assessment. Noise predictions provided for the wildlife assessment are presented here for information purposes only.

The effects of traffic on public roadways has been assessed separately (Volume B, Section 5.5).

3.5.4.3 Residual Impact Criteria

Criteria used for noise are the World Bank noise standards for mining activity:

- an hourly L_{eq} noise level of 55 dBA between 7:00 am and 10:00 pm (daytime) and;
- an hourly L_{eq} noise level of 45 dBA between 10:00 pm and 7:00 am (nighttime); or
- a maximum increase in background noise levels of 3 dBA (applied where background is higher than 55 or 45 dBA respectively).

Criteria are applied at receptors (homes or communities) outside the project boundary. At the mine site, the boundary is at the outer edge of a 300 m buffer zone.

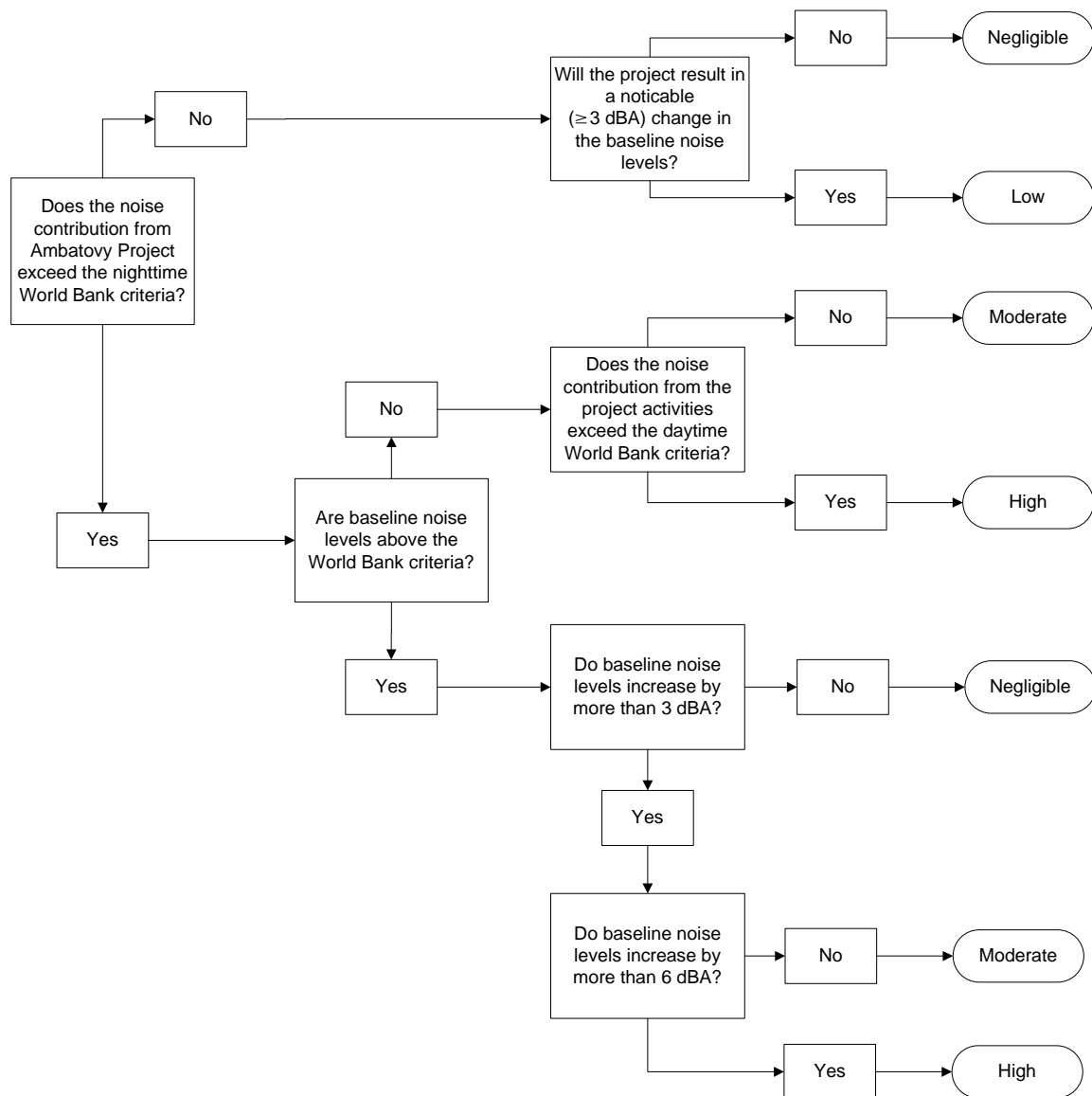
Residual impacts are determined at specific community receptors based on World Bank criteria. The parameters used to determine environmental consequence at the community receptors are direction, magnitude, geographic extent, duration, reversibility and frequency. The only parameter that has a unique definition for noise is magnitude. The impact magnitude ratings are also based on the World Bank criteria:

- negligible: predicted noise levels are below the WB criteria and will not affect baseline noise levels;

- low: predicted noise levels are below the WB criteria but will increase period (day or night) baseline noise levels, (where baseline levels are below WB criteria);
- moderate: predicted noise levels are above the WB nighttime criteria but below the daytime criteria. Where baseline levels are above WB criteria, noise levels increase by more than 3 dBA; and
- high: predicted noise levels exceed both the WB day time and nighttime criteria. Where baseline levels are above WB criteria, noise levels increase by more than 6 dBA.

Figure 3.5-1 illustrates the noise impact magnitude decision process.

Figure 3.5-1 Noise Impact Magnitude Decision Tree



3.5.4.4 Mitigation

Mitigation or noise controls considered in the mine site assessment are as follows:

- terrain acting as a natural barrier;
- standard silencers on motorized equipment; and
- buildings at the power plant and mill acting as barriers.

3.5.4.5 Emissions

Sources of noise considered for the mine site assessment are summarized in Table 3.5-2.

Table 3.5-2 Dynatec Mine Sound Emissions

| Source | Type of Source | Sound Power [dBA] |
|--|----------------|-------------------|
| ore receiving - truck dumping | point | 113.0 |
| process water pumps ^(d) | point | 127.6 |
| ore preparation thickener | point | 120.6 |
| ore receiving motor | point | 103.7 |
| truck traffic north | line | 128.9 |
| truck traffic south | line | 127.2 |
| conveyor ^(a) | line | 106.8 |
| mine face pit ^(b) | area | 119.3 |
| primary scrubber area ^(c) | area | 129.4 |
| secondary scrubber area ^(c) | area | 128.4 |
| engine generator set area ^(c) | area | 131.8 |
| slurry pump house ^(c) | area | 106.3 |
| Ambatovy waste stockpile ^(d) | area | 121.3 |

^(a) Sound Power for each system. There are six conveyor systems.

^(b) Sound Power for each face. The two mine faces are Ambatovy and Analamay. It was assumed that the mine fleet was divided 50% to Ambatovy and 50% to Analamay.

^(c) Process equipment will have noise mitigation and controlled to 85 dBA.

^(d) Sound Power for each stockpile. There are two stockpiles.

The model presents a snapshot of the expected continuous noise levels generated from the mine. To ensure that a “worst case” or highest expected noise level was assessed, the model is based on mine operations in years 13/14 when the highest number of vehicles and equipment will be in use. Mine face activity was assumed to be at the top lift in the pit, where the pit wall does not effectively shield noise. Other factors that were considered in the model are terrain, meteorological conditions and ground conditions.

3.5.4.6 Results

Predicted noise levels at community receptors due to mining activity are presented in Table 3.5-3.

Table 3.5-3 Predicted Noise Levels-Mine Site

| Location | Sound Level [dBA] |
|-------------|-------------------|
| Behontsa | 31 |
| Berano | 42 |
| Sahamalotra | 31 |

Predicted noise levels are also presented as a noise map in Figure 3.5-2.

3.5.4.7 Residual Impact Analysis

The basis for the analysis of noise impacts is both a comparison of predicted noise levels to World Bank criteria and a determination of the amount of change in baseline noise levels. Table 3.5-4 compares the predicted noise levels to the World Bank criteria. Table 3.5-5 provides an analysis of the amount of change in baseline noise levels.

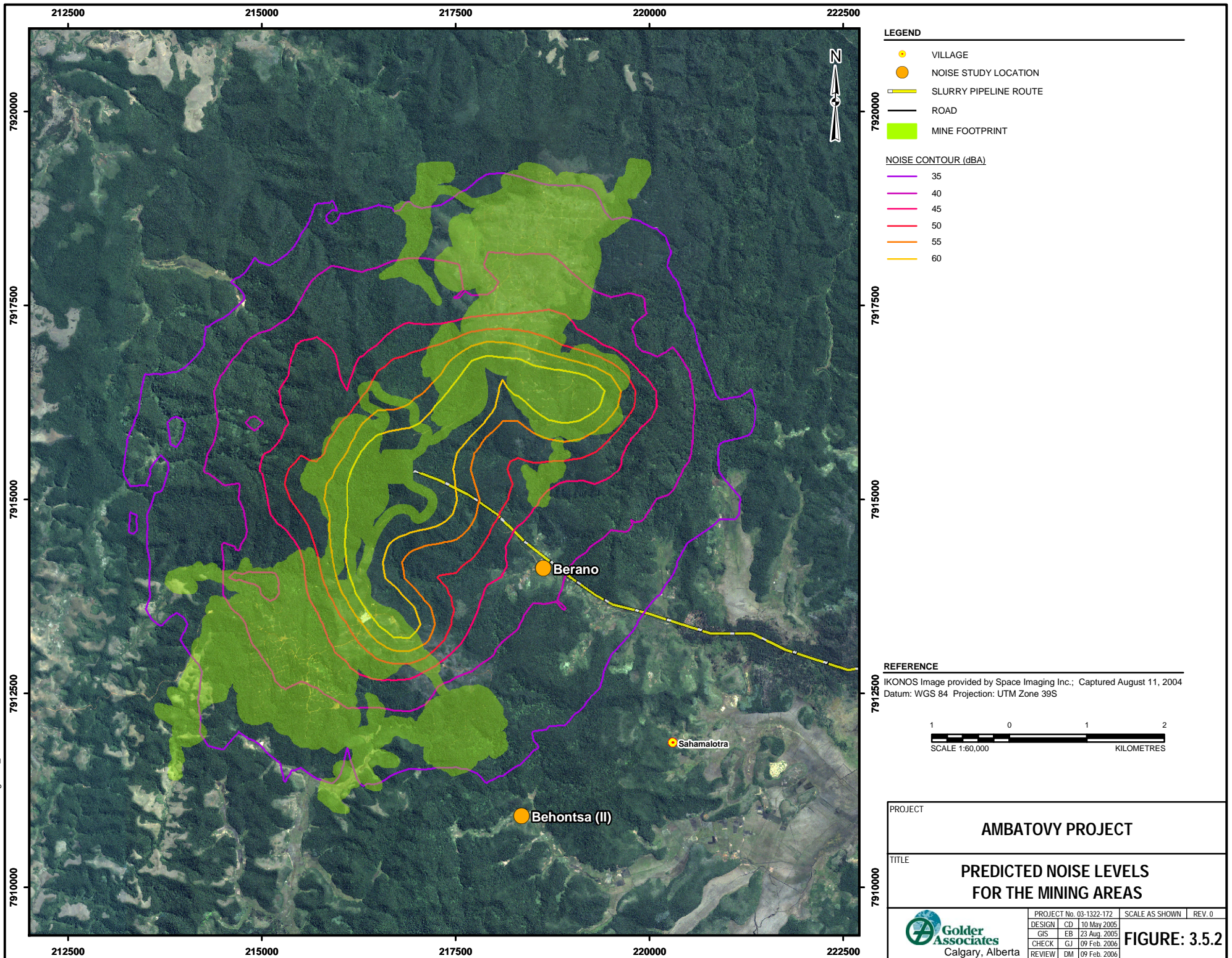
Table 3.5-4 Comparison of Predicted Noise Levels with World Bank Criteria, Mine Site

| Location | Sound Level [dBA] | World Bank Criteria [dBA] | | Meets Criteria |
|-------------|-------------------|---------------------------|-------|----------------|
| | | Day | Night | |
| Behontsa | 31 | 55 | 45 | yes |
| Berano | 42 | 55 | 45 | yes |
| Sahamalotra | 31 | 55 | 45 | yes |

Table 3.5-5 Expected Change in Baseline Noise Levels, Mine Site

| Location | Period | Period L_{eq} [dBA] | Predicted Project Noise Level [dBA] | Combined Noise Level [dBA] | Amount of change [dBA] |
|-------------|--------|-----------------------|-------------------------------------|----------------------------|------------------------|
| Behontsa | day | 42 | 31 | 42 | 0 |
| | night | 34 | 31 | 36 | +2 |
| Berano | day | 41 | 42 | 45 | +4 |
| | night | 40 | 42 | 44 | +4 |
| Sahamalotra | day | 41 | 31 | 41 | 0 |
| | night | 40 | 31 | 40 | 0 |

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The impact magnitudes determined using Figure 3.5-1 range from negligible to low at all community receptors. The World Bank nighttime noise criteria will be met at all communities, although background noise levels in Behontsa and Berano are predicted to increase. The resulting residual impacts range from negligible to low and are summarized in Table 3.5-6.

Table 3.5-6 Residual Impact Classification - Noise

| Community | Direction | Magnitude | Geographic Extent | Duration | Reversibility | Frequency | Environmental Consequence |
|-------------|---|---|--|--------------------------------------|---|-------------------------------------|---------------------------|
| Behontsa | negative: an increase in noise levels | negligible: no noticeable increase in background noise levels; all noise below World Bank criteria | local: at specific community receptors according to World Bank criteria | medium-term: 3 to 30 years | reversible noise is stopped once project activity stops | high: occurs continuously | negligible |
| Berano | negative: an increase in noise levels | low: background noise levels increased by over 3 dBA all noise below World Bank criteria | local: at specific community receptors according to World Bank criteria | medium-term: 3 to 30 years | reversible noise is stopped once project activity stops | high: occurs continuously | low |
| Sahamalotra | negative: an increase in noise levels | negligible: no noticeable increase in background noise levels; all noise below World Bank criteria | local: at specific community receptors according to World Bank criteria | medium-term: 3 to 30 years | reversible noise is stopped once project activity stops | high: occurs continuously | negligible |

3.5.4.8 Prediction Confidence

The modelling of outdoor noise attenuation is conducted using standard algorithms and assumptions that tend to simplify the acoustic environment. Noise, whether natural or man-made, is normally variable over time. The algorithms and the L_{eq} indicator account for that variability, but do not predict it. The variation of noise sources over time can be addressed in the CadnaA model in many ways, depending on the noise source being assessed and the level of detail required.

The quality and relevance of predictions from the noise model is dependant on the data inputs. For the assessment, noise sources were established with actual field measurement or vendor sound emission data where possible to ensure the accuracy of sources. Modelled noise levels for the existing activity on the site were compared with background noise data to ensure the simulations were representative of the site.

The CadnaA model was designed to predict outdoor noise in accordance with International Standards Organization (ISO) 9613 (1&2): *Attenuation of Sound During Propagation Outdoors* (ISO 9613) as well as several international and European acoustic standards. The ISO 9613 method will predict noise

attenuation to within ± 3 dBA. Supplier literature and third-party publications do not verify this level of accuracy for the CadnaA model. To validate that the CadnaA model meets the ISO standard, an independent study was done. This study verified the model calculates the ISO method correctly and that simulations of outdoor noise levels match field measurements of a known source to within ± 3 dBA.

3.5.4.9 Monitoring Plans

Since noise impacts are predicted to be low to negligible, a monitoring program for noise is not considered necessary. As part of the ongoing community relations program, a process for addressing noise complaints will be developed. Should a noise complaint be received during project operations, an investigation will be conducted to identify the source of the noise and determine possible solutions, if necessary. The investigation may include measurement/monitoring, interviews or modelling.

3.5.5 Conclusions

Key Question N-1 asked: What Effect Will Noise from the Ambatovy Mine Activity Have on Sensitive Receptors? The effects of project noise levels were determined by:

- establishing the existing noise levels at specific receptors for noise;
- predicting the amount of sound generated by the major sources of sound from the project; and
- evaluating the resulting noise levels at specific receptors.

Low to negligible impacts were predicted for the project. All predicted noise levels met the World Bank criteria at the three specific receptors identified for the assessment. Baseline noise levels will not change for Sahamalotra. Low-impact magnitudes were predicted for Behontsa and Berano as baseline noise levels are expected to increase by up to 4 dBA. Since World Bank criteria are met but a change in baseline noise levels is expected, the effects of project noise are considered to be of low environmental consequence.

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 mine, as per the Ambatovy Project (the project) Terms of Reference.

3.6.2 Study Area

The mine Local Study Area (LSA) for natural risks includes the mine and immediately adjacent watershed areas as presented in Volume A, Figure 7.2-1. Natural hazards such as earthquakes and cyclones, can originate from a wide regional area that was studied as appropriate to determine the potential impacts at the mine site.

3.6.3 Baseline Summary

The Environmental Assessment is based on a separate study on natural hazards and risk assessment for the mine site (Knight Piesold 2005a, which is provided in Volume I, Appendix 6.1). In this reference study, the baseline for the mine site setting is described in terms of location and topography, mine site facilities, existing land use, climate and seismicity. Potential natural hazards, potential consequences of failure due to natural hazards and risks downstream of the mine site were assessed. Resources downstream of the mine site include small human settlements, potable water and agricultural land, and natural areas such as the Torotorofotsy Wetlands.

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 2005a) 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 (Volume A, Section 6) were also included in these hazard scenarios.

Seismic Hazards

Ground motions from an earthquake could trigger:

- A landslide in the watersheds of the collection or clarification ponds which could cause overtopping or breaching of the embankments.
- Liquefaction of the embankments and/or foundation which could cause overtopping or breaching of the embankments.
- Liquefaction of the waste dump and/or excavated slopes which could cause a flow slide.

Hydrological Hazards

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

- A landslide in the watersheds of the collection or clarification ponds which could cause overtopping or breaching of the embankments.
- Inundation of the collection or clarification ponds where the overflow spillways would pass the maximum designed flows in a safe and controlled manner. This would cause flooding downstream of the mine site.
- Inundation of the collection or clarification ponds where the overflow spillways could not pass the storm flows in a safe and controlled manner. This could cause overtopping or breaching of the embankments.
- Erosion and failure of the embankments which could cause release of water to the environment.
- The creation of a large wave from high winds that could overtop or breach the embankments.
- Erosion and failure of the waste dumps or excavated slopes which could cause a flow slide.

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 collection or clarification ponds which could cause overtopping or breaching of the embankments.

- A landslide along the embankments due to poor foundation conditions, excessive seepage (piping) and/or oversteepening of the embankments that could cause overtopping or breaching of the embankments.
- A landslide at the waste dumps or excavated slopes due to poor foundation conditions or oversteepening of the slopes which could cause a flow slide.

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 Mine?

3.6.5 Impact Assessment

3.6.5.1 Assessment Methods

A risk assessment was completed for natural hazards (Knight Piesold, 2005a) 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:

Ranking Category “Extremely Low” signifies negligible occurrence potential.

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, 2005a). The design basis and criteria for the mine site are based on international standards for the design of dams, waste dumps and excavated slopes to minimize risk to within recognized acceptable levels for downstream public and environmental resources.

Risk mitigations were identified for all potential natural hazard scenarios. Mitigation for both the collection and clarification ponds and the waste dumps and excavated slopes 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, waste overburden and foundation materials;
- slope stability analyses;
- international standards for acceptable Factors of Safety;
- design earthquake 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; and
- storm routing design.

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 an extremely low overall risk rating. This is largely due to the fact that Madagascar is in a region of low seismic hazard and that application of conservative seismic design parameters will address seismic concerns.

Potential failure and subsequent consequences due to geotechnical issues are also rated in the Extremely Low category with the exception of one that is rated in the low range of the 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 sediment-laden water will be Extremely Low.

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

For the hydrologic hazard source, half of the failure mode and resulting consequences fall in the Extremely Low category and half of the results fall within the low range of the Low category. In general, the likelihood of a hydrologic event is considered higher than a geotechnical or seismic event. This is due to the fact that the mine site is located in an area prone to extreme cyclones. In addition, there is generally less understanding of precipitation or meteorological patterns than understanding of seismic and geotechnical conditions. The highest overall risk rating estimated is for heavy rains causing maximum flows over clarification pond spillways (Low category). Potential for overtopping and/or breaching of the water pond embankment due to heavy rainfalls also has a risk rating in the Low category.

3.6.5.5 Impact Analysis

Residual Impacts

Following mitigation, the residual risks during all project periods are both 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 Section 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 mine 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 mine on hydrogeology, as per the Ambatovy Project (the project) Terms of Reference.

3.7.2 Study Area

The mine Local Study Area (LSA) for hydrogeology is the area included in the numerical model by GCS (Pty) Ltd., as shown on Drawing No. 3.1.3 included in Volume I, Appendix 7.2. It is a 100 square kilometer area centred on the Ambatovy and Analamay ore deposits and includes river systems that feed that Mokaranana and Torotorofotsy wetlands.

3.7.3 Baseline Summary

3.7.3.1 Introduction

Baseline conditions in the mine area were characterized by carrying out a hydrogeologic site investigation. Details can be found in Volume I, Appendix 7.1.

3.7.3.2 Methods

Groundwater Consulting Services (GCS) (Pty) Ltd. was contracted to perform a hydrogeological investigation at the mine site. An initial study was completed in December 2004 during the dry season, with additional aquifer tests completed during the rainy season (April 2005).

The aim of the investigation was to characterize the hydrogeological environment and to predict the potential influence of the proposed mining activities on the groundwater regime. The hydrogeological investigation included:

- Drilling and installation of groundwater monitoring wells;
- Hydrocensus to measure the groundwater levels in boreholes;
- Aquifer testing on the test pumping boreholes; and
- Data analysis.

3.7.3.3 Results

Based on the hydrogeological and lithological conditions documented during the study, four layers were delineated. These layers are:

Ferricrete - This is a surficial layer that forms a few metres (average 4 m) thick crust over the top of the deposit. The ferricrete is localized and does not extend throughout the whole of the study area.

Ferralite (Laterite) - The ferralite layer underlies the ferricrete and is a red-brown clay with an average thickness of 40 m. The ferralite extends through the whole of the study area, and is considered to contain large volumes of groundwater. However, due to the low permeability nature of the ferralite, the aquifer is low yielding.

Saprolite - This is the transition zone between the ferralite and bedrock where the rock is already weathered but not completely altered into the red-brown clay layer that constitutes the ferralite. The alteration often takes place along fractures and/or faults, which gives this layer an irregular appearance.

Bedrock - This comprises ultrabasic primary rocks such as peridotites and gabbros intruded by numerous intrusive dykes, and it has a secondary porosity resulting from fractures, joints and faults.

A conceptual groundwater model for the mine area is shown on Drawing No. 3.1.4 in Volume I, Appendix 7.2. The ferricrete generally has the highest transmissivity and therefore 50 to 60 percent of the groundwater flows within the ferricrete layer to discharge along the edges of the plateau to surface water sources. Residual groundwater that infiltrates vertically through the ferricrete into the ferralite eventually reaches the ferralite associated groundwater table. The groundwater migrates downward within the ferralite to the saprolite transition zone and then travels at a near horizontal gradient to discharge into surface water bodies.

The Ambatovy and Analamay ore bodies are situated on a topographic high which forms a surface water and groundwater divide. Therefore, groundwater from the proposed pit areas would be expected to flow concentrically away from the ore bodies. A relationship between groundwater levels observed during the hydrocensus and the topography is shown on Drawing No. 3.1.2 in Volume I, Appendix 7.2. The figure shows a linear trend when comparing the topographic elevation versus static water level data for each of the aquifers. As shown, there are distinctive water tables associated with each of the aquifers. A general

groundwater contour map of the study area has been compiled and is shown on Drawing No. 3.1.3 in Volume I, Appendix 7.2. The figure shows that groundwater flow direction in the area of interest varies due to the hilly nature of the site. In general, groundwater level is dependant on the topography.

The groundwater is a Magnesium-Bicarbonate type water, and is typical of groundwater that has been recently recharged by rainfall. The low electrical conductivity (EC) and total dissolved solids (TDS) also indicate water that is recently recharged. The relatively high magnesium, bicarbonate and silica concentrations are indicative of interaction of the groundwater with the ultrabasic bedrock.

Table 3.7-1 summarizes the groundwater sampling results to date. Some data have been deemed questionable, as discussed in Volume I, Section 7.1, Attachment 2. Attempts were made to determine the proportion of chromium that is present as hexavalent chromium, but due to sampling and analytical difficulties the results remained inconclusive. Regardless, the groundwater quality data show that total chromium and nickel in the groundwater are both elevated in the natural condition, at concentrations above the WHO provisional drinking water guidelines of 0.05 mg/L and 0.2 mg/L, respectively.

The presence of the elevated chromium can be attributed to the natural occurrence of chromium in the ultramafic lithologies underlying the site, and the weathered saprolitic and lateritic soils derived from the ultramafic rocks. Chromium naturally occurs almost exclusively in its trivalent state (Cr^{3+}), however, and the occurrence of Cr^{6+} is normally attributed to industrial activity. Cr^{6+} is known to occur naturally as well, and while the mechanism for its occurrence is not fully understood (Gray, 2003), a prominent hypothesis is that manganese oxides in the soil can act as oxidising agents to convert Cr^{3+} to Cr^{6+} (McBride, 1994).

Table 3.7-1 Mine Site Groundwater Quality

| Borehole ID. | | DAN245H | | | | | DAM126H | | | | Korean Pit | AMB046H | | AMB129H / AMB113H | | DAN106H |
|------------------|------------------------|-----------|--|--|---------------------|---|--|--|---------------------|--|---------------------|---------------------|--|---------------------|-----------|-----------|
| Sample Date | | 7/31/2004 | 3/26/2005 | 3/26/2005 | 4/19/2005 | 4/19/2005 | 3/27/2005 | 3/27/2005 | 4/20/2005 | 4/20/2005 | 3/26/2005 | 4/21/2005 | 4/21/2005 | 4/21/2005 | 4/28/2005 | 4/27/2005 |
| Laboratory | | | Inspectorate M&L | Dynatec | Inspectorate M&L | JIRAMA | Inspectorate M&L | Dynatec | Inspectorate M&L | JIRAMA | Inspectorate M&L | Inspectorate M&L | JIRAMA | Inspectorate M&L | JIRAMA | JIRAMA |
| Comments | | | Duplicate, Cr(VI) sample acidified | Duplicate, Cr(VI) sample acidified | Duplicate | Duplicate, Cr(VI) sample not acidified | Duplicate, Cr(VI) samples acidified | Duplicate, Cr(VI) samples acidified | Duplicate | Duplicate, Cr(VI) sample not acidified | | Duplicate | Duplicate, Cr(VI) sample not acidified | | | |
| pH | | 7.8 | | | 7.8 | | | | 6.4 | | | 5.3 | | 6.6 | 6.34 | 6.39 |
| EC | mS/m | 15.8 | | | 13.6 | | | | 6.02 | | | 3.36 | | 11.0 | 7.05 | 12.97 |
| TDS | mg/l | 190 | | | 82 | | | | 44 | | | 20 | | 80 | | |
| hardness | mg/l CaCO ₃ | 57 | | | 56 | | | | 23 | | | 8.4 | | 43 | | |
| Ca | mg/l Ca | 0.4 | | | 1.2 | 3.6 | | | 2.4 | | | 0.9 | 1.2 | 0.4 | 10.8 | 3.6 |
| Mg | mg/l Mg | 13.5 | | | 12.8 | 18.23 | | | 4.2 | | | 1.5 | 2.19 | 10.2 | 7.78 | 21.14 |
| Na | mg/l Na | 2.2 | | | 0.6 | 2.3 | | | 0.8 | | | 0.7 | 2.3 | 1.3 | 2.3 | 2.3 |
| K | mg/l K | <0.1 | | | <0.1 | | | | 0.1 | | | 0.5 | | 0.2 | | |
| alkalinity | mg/l CaCO ₃ | 56 | | | 52 | | | | 16 | | | 8 | | 32 | | |
| HCO ₃ | mg/l HCO ₃ | 68 | | | 63 | 74.42 | | | 20 | | | 10 | 6.1 | 39 | 43.92 | 40.26 |
| Cl | mg/l Cl | 2.6 | | | 3.1 | 3.55 | | | 3.1 | | | 2.6 | 3.55 | 4.1 | 3.55 | 3.55 |
| SO ₄ | mg/l SO ₄ | 2.4 | | | 2.1 | 0.00 | | | 3.4 | | | 1.9 | 0.00 | 2.9 | 0.00 | 52.36 |
| cations | meq/l | 1.23 | | | 1.14 | 1.78 | | | 0.50 | | | 0.21 | 0.34 | 0.92 | 1.28 | 2.02 |
| anions | meq/l | 1.24 | | | 1.16 | 1.32 | | | 0.49 | | | 0.28 | 0.20 | 0.82 | 0.82 | 1.85 |
| Ag | mg/l Ag | <0.004 | | | <0.004 | | | | <0.004 | | | <0.004 | | <0.004 | | |
| As | mg/l As | 0.06 | | | <0.02 | | | | <0.02 | | | <0.02 | | <0.02 | | |
| Cr | mg/l Cr | 0.13 | 0.32 | 0.286 | 0.10 | | 0.19 | 0.098 | 0.29 | | <0.01 | 0.06 | | 0.05 | | |
| Cr (VI) | mg/l Cr | | 0.22 | 0.183 | | 0.08 | 0.06 | 0.098 | | 0.22 | <0.01 | | 0.06 | | 0.014 | 0.065 |
| Cu | mg/l Cu | <0.002 | | | <0.002 | | | | 0.002 | | | <0.002 | | <0.002 | | |
| Fe | mg/l Fe | 0.08 | | | 0.12 | | | | 0.17 | | | 0.06 | | 0.74 | 10 | 0.3 |
| Hg | mg/l Hg | <0.001 | | | <0.001 | | | | <0.001 | | | <0.001 | | <0.001 | | |
| Mn | mg/l Mn | 0.005 | | | <0.001 | | | | 0.02 | | | 0.10 | | 0.22 | 0.00 | 0.76 |
| Ni | mg/l Ni | | 0.05 | | 0.07 | | 0.12 | | 0.32 | | <0.003 | 0.10 | | 0.74 | | |
| Se | mg/l Se | 0.02 | | | <0.03 | | | | <0.03 | | | <0.03 | | <0.03 | | |
| Si | mg/l Si | 19.3 | | | 15.6 | | | | 6.89 | | | 1.0 | | 13.9 | | |
| Zn | mg/l Zn | <0.005 | | | 0.18 | | | | 0.16 | | | 0.02 | | 0.15 | | |
| NO ₃ | mg/l NO ₃ | | | | 0.7 | 0.00 | | | 0.3 | | | 4.4 | 0.48 | 2.8 | 0.04 | 0.03 |
| NO ₃ | mg/l N | 0.6 | | | 0.2 | | | | <0.1 | | | 1.0 | | 0.6 | | |
| NO ₂ | mg/l NO ₂ | <0.1 | | | <0.1 | | | | <0.1 | | | <0.1 | | <0.1 | | |
| B | mg/l B | 0.03 | | | <0.006 | | | | <0.006 | | | <0.006 | | <0.006 | | |
| F | mg/l F | <0.1 | | | <0.1 | | | | 0.2 | | | <0.1 | | <0.1 | | |
| PO ₄ | mg/l P | 0.6 | | | <0.1 | | | | 0.1 | | | 0.2 | | 1.5 | | |

Nickel concentrations in groundwater appear to exceed the WHO provisional guideline for drinking water quality, ranging from 0.05 to 0.74 mg/L compared with the WHO provisional guideline of 0.02 mg/L. The exception is the Korean Pit, where nickel was <0.003 mg/L, below the WHO provisional guideline.

The WHO guideline for nickel is provisional because of the lack of information on health effects. The US EPA maximum level for drinking water is 0.1 mg/L and a guideline level for the Canadian Drinking Water Quality Guidelines is under preparation (Water Quality Section, Section 3.9 of this volume).

3.7.4 Issue Scoping

The main potential issues relating to hydrogeology are:

- changes to the groundwater system (flow and quality) due to dewatering of the open pits during mining; and
- effects the changes to the groundwater system may have 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 hydrogeology.

The Key Questions for the hydrogeology surrounding the mine are:

- | | |
|--------------------------|--|
| Key Question HG-1 | What Effect Will the Mine Have on Groundwater Flows and Quality at the Mine Site? |
| Key Question HG-2 | What Effect Will the Mine Have on Groundwater Flows and Quality at the Surrounding Area, particularly the Torotorofotsy Wetlands? |

3.7.5 Impact Assessment

Project activities during construction, operations and closure will result in the following: i) localized dewatering of groundwater aquifers around the mine site; ii) changes in groundwater quality; and iii) subsequent effects on the hydrology of the Torotorofotsy Wetlands.

During construction there will be little impact on groundwater resource, as disturbance to the landscape primarily involves site clearing and the development of infrastructure. Mine runoff collection ponds will be constructed and surface

runoff characteristics and natural drainage patterns may be affected, which may have a very minor influence on groundwater.

During operations, groundwater will be abstracted from the active mining areas and will be collected in detention and clarification ponds prior to discharge to the receiving environment. A low reduction in groundwater contributions to surface water baseflows will occur: 6.6% and 8.3% reduction of flow in the affected rivers, for the wet and dry seasons respectively. This will ultimately translate to a low reduction of the groundwater contribution to the total amount of runoff to the Mokaranana and Torotorofotsy wetlands. The groundwater reduction will be offset by increases in surface water runoff from the mine site.

The abstracted groundwater will be pumped to mine runoff control ponds. Regular monitoring will be carried out at the outlet of each mine water runoff control pond, and a portion of the water will be removed from the ponds and routed through the ore preparation plant to ensure that chromium and nickel in the water discharged from each of ponds remains below WHO provisional drinking water guidelines. Water diverted to the ore preparation plant will be substantially diluted by process water derived from the Mangoro River. Additional detail is provided in the discussion on water quality in Volume B, Section 3.9.

The elevated chromium VI and nickel concentrations in groundwater are a natural condition, and while pit dewatering during mining will affect downgradient groundwater flows to some degree, no changes to groundwater quality are envisaged.

The closure scenario involves discontinuing any mine dewatering and a gradual recovery of the groundwater aquifers. Mined areas will be recontoured as necessary and revegetated. Pond embankments will be breached and returning surface runoff to the natural receiving streams. Runoff volumes may still be greater than under natural conditions due to changes in vegetation and infiltration.

3.7.5.1 Assessment Methods

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

The numerical model was used to predict the influence of the mining activities on the groundwater environment. Hydrogeological parameters compiled from the

site investigations were used to develop a model to predict impacts from the proposed mine development. This included incorporating measured groundwater levels and transmissivities obtained from the aquifer tests within the model. Calibration of the model (matching calculated groundwater levels to observed groundwater levels) proved to be difficult. During the calibration process the aquifer parameters such as transmissivity and recharge percentage were varied within realistic values in order to obtain the best possible correlation between the calculated and observed groundwater levels.

3.7.5.2 Impact Description Criteria

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

Table 3.7-2 Impact Description Criteria and Numerical Scores for 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.

3.7.5.3 Mitigation

Project design involves the development of the open pits in phases. This approach requires localized dewatering of active work areas in a phased approach rather than constant dewatering of a large area. This will reduce the amount or rate of groundwater withdrawal from storage in the aquifer and facilitate more expedient recovery of groundwater levels at closure.

At closure, disturbed areas will be restored by providing natural vegetation and topography, to re-establish natural runoff conditions and ensure that drainage areas of each sub-watershed are close to pre-development values.

3.7.5.4 Results for Key Question HG-1: What Effect Will the Mine Have on Groundwater Flows and Quality at the Mine Site?

Dewatering that will occur during mining will result in a cone of depression that will advance to a maximum distance of 800 m from the mining area. It is expected that the ferricrete layer will be temporarily dewatered in the vicinity of mining activities between rainfall events and in the dry season, but owing to the high transmissivity of this layer it will be recharged quickly by rainfall and will therefore provide almost continuous inflow of seepage into the mining area.

The maximum drawdown within the ferralite aquifer is expected to be approximately 30 m. The drawdown cone areas at the end of mining are shown on Drawing No. 3.3.6 in Volume I, Appendix 7.2.

Active mining in the open pits will be complete by Year 20 of operation, after which the operation will focus on the processing of stockpiled low-grade ore. Groundwater abstraction will end and regional groundwater levels will recover over time.

The ferricrete that forms the upper aquifer is only 4 m thick and has a high hydraulic conductivity. As such, it is expected to recover to the pre-mining state within 5 to 20 years depending on the locality. The underlying ferralite aquifer will recover slowly due to the low transmissivity of the material. It is expected that groundwater levels will recover to pre-mining conditions within approximately 5 to 75 years depending on the locality. The groundwater recovery curves for monitoring wells in the ferricrete and ferralite are shown on Drawing No. 3.3.9 in Volume I, Appendix 7.2.

As discussed in Section 3.7.5, groundwater at the mine site contains elevated Cr and nickel concentrations above WHO provisional drinking water guidelines in its natural condition. Groundwater abstracted from the open pits report to mine water collection ponds. The water quality of surface waters is discussed in Volume B, Section 3.9.

Groundwater abstraction and other mine operations are not expected to adversely affect groundwater quality, although the possibility exists of accidental releases or spills to negatively impair groundwater, depending on the type of material, magnitude, duration, weather conditions and location of the spill or release. Mitigation has been identified to reduce and minimize the effects of these events in Section 3.9.5.4. Furthermore, environmental management systems will be developed and implemented to minimize potential occurrence, characterize water

and sediment quality changes, and reduce likely effects, if such an event should occur.

3.7.5.5 Results for Key Question HG-2: What Effect Will the Mine Have on Groundwater Flows and Quality at the Surrounding Area, particularly the Torotorofotsy Wetlands?

Mine dewatering will influence the volume of water that flows into the Torotorofotsy and Mokaranana wetland systems. The Mokaranana wetland system is interconnected to Torotorofotsy and any influence on Mokaranana will influence Torotorofotsy as well. Groundwater contributions to the baseflow of affected upper river watersheds that feed Mokaranana or Torotorofotsy will be reduced by approximately 7%. The affected portions of the watersheds or area of influence is shown on GCS Drawing No. 3.3.7 in Volume I, Appendix 7.2. The quality of groundwater contributions to the river watersheds will not be affected by mining operations.

Based on this reduction in baseflow contribution and actual measured river flow volumes in the Torotorofotsy and Mokaranana wetlands, the reduction in river inflow into the wetland systems from the rivers that are affected have been calculated and are shown in Table 3.7-3.

Table 3.7-3 Reduction in Affected River Inflow into the Wetland Systems due to Baseflow Contribution Decrease

| | Dry Season | | Wet Season | | Average | |
|-------------------------------------|---|--|---|--|---|--|
| | observed (10apr2004 to 14dec2004) | calculated with mining influence | observed (15dec2004 to 23feb2004) | calculated with mining influence | observed (10apr2004 to 23feb2005) | calculated with mining influence |
| Mokaranana Area (QESF-101) | 0.012 ³ /sec | 0.011m ³ /sec | 0.225m ³ /sec | 0.209m ³ /sec | 0.015m ³ /sec | 0.014m ³ /sec |
| Torotorofotsy Area (QESF-103) | 0.13 m ³ /sec | 0.12 m ³ /sec | 0.303m ³ /sec | 0.282m ³ /sec | 0.155m ³ /sec | 0.144m ³ /sec |

While up to a 6.6% to 8.3% reduction of groundwater contributions to surface water baseflows downstream the mine site may occur (7% based on average flows), groundwater abstracted in mine dewatering during operation will be released into mine runoff collection ponds and will eventually report to surface drainage features. In addition, runoff from the mine site is expected to be higher than under baseline conditions due to land disturbance associated with mine development. Mine site hydrology is described in the subsequent section

(Volume B, Section 3.8). The minor reduction in groundwater inflow volumes into the wetland will be offset by an increase in surface runoff that will occur during mining.

3.7.6 Impact Analysis

3.7.6.1 Residual Impacts

During construction, negligible impacts to groundwater resources will occur as influence to groundwater will be limited to excavation of mine water collection ponds that could provide minor increased seepage to groundwater.

During operations, extraction of groundwater from the active areas of mining will result in temporary dewatering of the groundwater aquifers. It will also reduce groundwater contributions to upper watersheds of affected rivers that feed the Mokaranana and Torotorofotsy wetlands by up to 7%. The reduction of baseflow contributions (low impact) will be offset by increased runoff from the mine area. Increases in surface flows in the Torotorofotsy River at the inlet to the wetlands will be less than 4% during operations and about 2% for post-closure conditions (Volume B, Section 3.8).

Groundwater aquifers will recover in Year 20 of operations when active mining in the open pits ceases. The estimated time for complete recovery of groundwater levels to pre-mining state is 5 to 20 years (ferricrete aquifer) and 5 to 75 years (ferralite aquifer), depending upon the location. The remnant open pits and the removal of materials during mining will result in an altered landscape that will permanently influence the groundwater regime to some degree. The degree of reduction of groundwater contributions to river baseflows will lessen from the 6.6% to 8.3% as the groundwater aquifers recover such that the long-term influence on groundwater flow will be less than that during operations.

Residual impacts are presented in Table 3.7-4. Residual impacts to groundwater flows and groundwater quality at the mine site is of negligible to low environmental consequence. Residual impacts of changes in groundwater contributions to the Mokaranana and Torotorofotsy Wetlands during operations is of low magnitude, medium-term in duration and of high frequency, ultimately obtaining a moderate rating in terms of environmental consequence.

Table 3.7-4 Residual Impact Classification for Hydrogeology

| Phase | Direction | Magnitude | Geographic Extent | Duration | Reversibility | Frequency | Environmental Consequence |
|--|-----------|------------|-------------------|-------------|---------------|-----------|---------------------------|
| Issue: Changes in Groundwater Flows and Quality at the Mine Site | | | | | | | |
| construction | neutral | negligible | local | short-term | reversible | low | negligible |
| operations | negative | low | local | medium-term | reversible | high | low |
| closure | neutral | negligible | local | long-term | reversible | high | negligible |
| Issue: Changes in Groundwater Flows and Quality on the Mokaranana and Torotorofotsy Wetlands | | | | | | | |
| construction | neutral | negligible | regional | short-term | reversible | low | negligible |
| operations | negative | low | regional | medium-term | reversible | high | moderate |
| closure | neutral | negligible | regional | long-term | reversible | high | negligible |

3.7.6.2 Prediction Confidence

The hydrocensus showed differentiation between the various groundwater aquifers, and a linear relationship was established between topographic elevations and static water level data. Further, the calculated transmissivities for the ferrallite and saprolite units are consistent with the findings of investigations in 1998-99. Matching calculated groundwater levels in the numerical model with observed groundwater levels during model calibration, however, proved difficult. Thus, aquifer parameters (transmissivity and recharge percentage) used in the numerical model were adjusted within realistic values to obtain the best possible correlation between the calculated and observed groundwater levels. The extent and depth of the expected groundwater drawdown is based on a lower transmissivity value used to fit the numerical model, and a higher calculated value for transmissivity would result in a larger zone of influence. The prediction confidence of medium is attributed to the groundwater model and the effect of mine dewatering on groundwater contributions to surface water baseflows and ultimately the wetland areas.

Overall, groundwater quality analyses completed to date show consistent trends between sample locations. However, based on evaluation of cation balance and other general chemistry parameters, some results have been deemed unreliable (GCS 2005, July 2005, Volume 1, Appendix 7.1). There is some uncertainty as to whether or not chromium measured in groundwater is present in its hexavalent form (Cr^{6+}), owing to the inherent difficulties in delivering an unpreserved groundwater sample to a laboratory for analysis of chromium (VI) as required by analytical standards. Nevertheless, water quality estimates as well as mitigation planned for the project has assumed conservatively that all chromium present is in its more toxic hexavalent form. Groundwater quality results are attributed a medium prediction confidence.

3.7.6.3 Monitoring

Monitoring of groundwater levels and key groundwater parameters in wells will continue through all phases of the project. In addition, downstream river flows and water levels in all of the water basins will be monitored as part of the hydrology monitoring program described in Volume B, Section 3.8.

3.7.7 Conclusions

Impacts to groundwater resources at the mine area will be of high magnitude but ultimately of low environmental consequence. Effects on the surrounding area are of low magnitude and ultimately of low environmental consequence.

3.8 HYDROLOGY

3.8.1 Introduction

Development of the mine will involve varying degrees of land disturbance, such as removal of vegetation, excavation and ground compaction. The mine will also include the construction of roads, buildings, parking and storage areas, waste dumps and other facilities. These disturbances will result in increased runoff rates and volumes from the area until reclamation activities and revegetation activities are complete. All runoff from the development will be collected in collection and clarification ponds prior to release to the environment.

Regional climate and hydrologic information have been compiled to characterize baseline conditions in the mine 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 mine is located along a drainage divide, at the headwaters of six watersheds. The hydrology local study area (LSA) includes the mine, Torotorofotsy Wetlands and buffer areas in all directions. As shown in Volume A, Section 7, Figure 7.2-1, the LSA also includes the water intake location on the Mangoro River.

3.8.3 Baseline Summary

3.8.3.1 Introduction

Baseline conditions in the mine 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 was collected over the March 2004 to March 2005 period at 12 locations in the mine area, including three stations along the Mangoro River. Discharge and water level measurements were collected monthly by a team of technicians in order to establish a rating curve for each location. Water levels were recorded on a daily basis by local assistants and were used to derive a time series of streamflow for each station. Daily water levels continue to be recorded at these locations.

3.8.3.3 Results

Long-term climate records are available near the mine site at Moramanga and at Andasibe (Perinet), while short-term records are available for the mine site. Derived monthly and annual precipitation for the mine is summarized in Table 3.8-1. The mean annual rainfall is estimated to be 1,700 mm. Historical records suggest that the annual rainfalls for 1:50 year dry and wet conditions vary from about 40% lower to 50% higher than the mean. Maximum daily rainfall for various return periods are shown in Table 3.8-2. Maximum daily rainfall amounts at the mine site are based on data from Andasibe (Perinet) and reflect the higher rainfall conditions at the mine relative to Moramanga. Maximum 24-hour rainfall amounts (Table 3.8-3) have been estimated by applying a factor of 1.08 to the daily maximum values. This factor was derived based on the short-term data available from the mine site.

Table 3.8-1 Derived Monthly and Annual Precipitation (mm) for the Mine

| Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Annual |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--------|
| 139 | 275 | 338 | 273 | 226 | 84 | 53 | 57 | 86 | 80 | 36 | 56 | 1,700 |

Table 3.8-2 Maximum Daily Rainfall

| Maximum Daily Rainfall (mm) for Various Return Periods ^(a) | | | | | |
|---|------|-------|-------|-------|--------|
| 2-yr | 5-yr | 10-yr | 20-yr | 50-yr | 100-yr |
| 113 | 168 | 214 | 266 | 346 | 419 |

^(a) Andasibe (Perinet) rainfall data 1963-1973.

Table 3.8-3 Maximum 24-Hour Rainfall Amount

| Maximum 24-hour Rainfall (mm) for Various Return Periods ^(a) | | | | | |
|---|------|------|-------|-------|--------|
| 2-yr | 5-yr | 10-y | 20-yr | 50-yr | 100-yr |
| 122 | 181 | 231 | 287 | 374 | 453 |

^(a) Maximum daily precipitation at Andasibe (Perinet) adjusted by a factor of 1.08 to convert to maximum 24-hour values.

Actual evapotranspiration (ET) at the mine site is estimated at 750 mm per year. Evapotranspiration rates for the Torotorofotsy Wetlands are expected to be closer to potential ET due to near-continuous water availability and are estimated at 900 mm/year. Based on data from 2004 to 2005 monitoring period, annual runoff for the mine, Torotorofotsy and the Mangoro areas is on the order of 500 to 800 mm.

The Mangoro River mean monthly and annual flows are shown in Table 3.8-4. Maximum and minimum daily flows are shown in Table 3.8-5.

Table 3.8-4 Mangoro River - Mean Monthly and Annual Flows

| River and Location | Drainage Area (km ²) | Period of Record | Mean Monthly flow (m ³ /s) | | | | | | | | | | | | Annual |
|-------------------------|----------------------------------|--------------------------|---------------------------------------|-----|-----|-----|-----|-----|-----|------|------|------|------|------|--------|
| | | | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | |
| Mangoro at Mangoro Gare | 3,600 | 1956-1997 ^(a) | 52.4 | 111 | 165 | 179 | 177 | 109 | 68 | 56.6 | 49.8 | 42.5 | 34.2 | 22.5 | 88.9 |

^(a) Madagascar Ministry of Public Works and Transport, Meteorology Branch 2005 (1979-1997 data).

Note: Numbers have been rounded for presentation purposes.

Table 3.8-5 Mangoro River - Extreme Daily Flow

| River | Drainage Area (km ²) | Period Of Record | Minimum Daily Flow, Qmin (m ³ /s) | | | Maximum Daily Flow, Qmax (m ³ /s) | | |
|-------------------------|----------------------------------|------------------|--|---------|---------|--|---------|----------------------|
| | | | 10 years | 5 years | 2 years | 2 years | 5 years | 10 years |
| Mangoro at Mangoro Gare | 3,600 | 1956-1979 | 20.2 | 21.3 | 23.3 | 440 | 810 | 1,210 ^(a) |

Source: Chaperon et al. 1993.

^(a) Extrapolated values.

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. As described in Volume A, the issues were identified, tracked and summarized at a high level for consideration in the impact assessment. The following hydrology issues were identified:

- 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, including the Torotorofotsy Wetlands).

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, fish health, vegetation (wetlands), and socio-economic components of the project.

The Key Questions for the hydrology surrounding the mine are:

| | |
|-------------------------|---|
| Key Question H-1 | What Effect Will the Mine Have on Flows and Water Levels in Water Bodies? |
| Key Question H-2 | What Effect Will the Mine Have on Sediment Levels in Water Bodies? |
| Key Question H-3 | What Effect Will the Mine Have on Torotorofotsy Wetlands Hydrology and Sediment Loading? |

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

3.8.5 Impact Assessment

3.8.5.1 Impact Pathway Evaluation

Project activities during construction, operations and closure may result in the following:

- changes in flows and water levels in receiving water bodies;
- changes in sediment levels; and
- subsequent effects on the hydrology and sediment loading of the Torotorofotsy Wetlands.

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 operations, the mine area runoff will be collected in detention and clarification ponds prior to discharge to the receiving environment. The ponds will be used as settling basins to limit the discharge and transport of suspended sediment to downstream reaches. Increases in surface runoff and decreases in

groundwater discharge could result in increased or decreased flows at downstream locations depending on the season.

Changes in flows and water levels, in conjunction with changes in sediment supply, may also affect the Torotorofotsy wetlands as well as downstream channel morphology as these systems adapt to reach new equilibrium conditions.

The closure scenario involves breaching the pond embankments and allowing surface runoff to drain to the natural receiving streams without being held for settling. Runoff volumes may still be greater than under natural conditions due to changes in vegetation and infiltration.

Changes in flows, water levels, and sediment levels in receiving water bodies may also affect water quality, fish and aquatic resources, socio-economics and land use. Water users are described in the socioeconomics and land use baseline reports (Volume K, Appendices 1.1 and 3.1) and effects of hydrologic changes on water users are described in the socioeconomic and land use EA reports (Volume B, Sections 5.1 and 5.3).

3.8.5.2 Assessment Methods

Changes in flows at the pond outlet locations were evaluated based on expected changes in watershed drainage area, land type, and related runoff characteristics. Baseline, operational and post-closure flows were derived using a simple hydrologic model that incorporates monthly rainfall and different runoff rates for different land types. The runoff coefficients applied account for gross water losses associated with evaporation, groundwater infiltration and local storage. The baseline runoff coefficients are based on 2004-2005 monitoring data, while coefficients for development conditions are based on professional judgment and experience with similar land types and developments.

Assumptions for Hydrologic modeling are based on current project design. The environmental team has worked closely with the engineering design team to develop reasonable assumptions of sufficient detail to enable monthly water balance simulation. Some aspects of engineering and therefore specific assumptions may change as a result of detailed engineering, however, mitigation will ensure that any impacts on flows, water levels, and sediment levels will be within the levels presented in this assessment. Details of model inputs and assumptions are provided in Volume I, Appendix 8-2.

Changes in streamflows at locations further downstream of the ponds were also evaluated. These were derived based on the expected pond outflows and additional tributary flow that enters the channel downstream of the ponds.

Changes in water depths, flow area and velocity were estimated at the hydrometric monitoring locations based on changes in flows at those locations and on available cross-sectional survey information. Water levels for various flows were calculated using the available rating curves, and were then translated to water depths and flow areas. Average velocities were calculated based on the flow rates, derived flow areas, and surveyed widths of the streams.

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 3.8-6.

Table 3.8-6 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:

- Monitor downstream flows to verify there is sufficient water for the receiving environment, and that any excess does not result in channel

instability; adjust operations and water management at the mine site if necessary.

- Provide drainage below the waste stockpile areas to assist in the conveyance of groundwater discharge to the downstream reaches.
- Manage the runoff collection and clarification ponds to replicate the natural variability associated with high and low flows.
- Provide storage in the runoff collection ponds to help attenuate peak flows associated with high rainfall events; use excess runoff generated by disturbed land to supplement mine water supply in order to moderate discharges.
- Use flocculant as needed to facilitate sedimentation of suspended sediment in runoff collected in the ponds.
- Monitor climate conditions and downstream flows as part of routine water management.
- Use erosion control measures to control sedimentation, including design of sedimentation ponds.
- Provide stable slopes and revegetate promptly to reduce erosion.
- Return areas to natural runoff conditions through reclamation.
- Configure closure topography to ensure that drainage areas of each sub-watershed are close to pre-development values.
- Direct streams and drainage paths to natural receiving water bodies.

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

Runoff from the mine site is expected to be higher than under baseline conditions due to land disturbance associated with mine development. All runoff generated in the disturbed basins will be collected in a series of ponds before being diverted or released to the environment. As noted above, flows can be augmented and diverted to the ore processing plant to establish acceptable seasonal flows that limit downstream effects. Model inputs and assumptions are provided in Appendix I, Section 8-2. The hydrologic analysis is based on the assumption that four of the six runoff collection ponds are constructed by the start of operations. The Analamay South (Torotorofotsy) and Northeast (Sakalava) ponds become operational by Year 10 when mining activity moves into those basins.

Flows Downstream of the Ponds

Expected changes in mean flows immediately (i.e., 500 m) downstream of the runoff collection ponds are summarized in Table 3.8.7. During operations the

ponds are predominantly operated to provide flows that, at a minimum, meet current average levels. Although a degree of excess runoff can be diverted to supplement mine water supply, these volumes would be released to the receiving streams if considered advantageous or not detrimental to the downstream environment

Changes in flows during periods in the wet season could be more pronounced due to high rainfall and large amounts of excess runoff. A portion of the excess runoff is used to supply the mine while the remainder is discharged to the receiving streams. During wet season periods and assuming all ore process plant water needs (about 1,000 m³/hr) are met from the ponds, the flows immediately downstream of the ponds are expected to increase by 0 to 5% in Year 4 depending on the basin, and increase by an average of about 21% in Year 20. The exception is the Torotorofotsy basin where changes in flows in Years 15 and 20 are limited to 14% and 12%, respectively, in an attempt to minimize effects on the downstream wetlands. The largest increases in flows occur in January in all basins.

The estimated changes in flow are based on the model inputs and assumptions given in Volume I, Appendix 8-2, Table 8.2-1. One of the key assumptions is the amount of water diverted from the ponds to the ore preparation plant. This water can be used to meet plant water requirements, and also includes runoff diversions from mine pits and waste stockpiles in the Analamay area to maintain acceptable water quality levels in pond release water. Throughout operations, downstream flows and physical conditions will also be monitored, and feedback will be solicited from downstream users to verify that any changes are considered acceptable.

Table 3.8-7 Change in Flows at 500 m Downstream of Runoff Collection Ponds

| Basin | Season | Operation Scenarios | | | | Post-Closure (after Year 28) |
|---------------|------------------|---------------------|-----------|------------------------|------------------------|---------------------------------|
| | | Year 4 | Year 10 | Year 15 | Year 20 | |
| Antsahalava | December - March | 0 to 2% | 12 to 17% | 11 to 20% | 12 to 21% | 23% ^(b) |
| | April-November | 0% | 0% | 0% | 0% | 23% ^(b) |
| Sahaviara | December - March | 0 to 5% | 12 to 16% | 16 to 20% | 18 to 22% | 20% |
| | April-November | 0% | 0% | 0 to 1% | 0 to 3% ^(a) | 20% |
| Sahamarirana | December - March | 0 to 3% | 9 to 17% | 14 to 20% | 16 to 22% | 24% ^(b) |
| | April-November | 0% | 0% | 0% | 0% | 24% ^(b) |
| Torotorofotsy | December - March | 0% | 5 to 10% | 3 to 8% | 10 to 12% | 8% |
| | April-November | 0% | 0% | 0% | 0 to 5% ^(a) | 8% |
| Sakalava | December - March | 0% | 3 to 8% | 12 to 20% | 0 to 8% | 12% |
| | April-November | 0% | 0% | 0% | 0% | 12% |
| Ankaja | December - March | 1 to 3% | 0 to 1% | 0 to 9% | 18 to 22% | 11% |
| | April-November | 0% | 0% | 0 to 2% ^(a) | 0 to 3% ^(a) | 11% |

^(a) Maximum changes occur in November; all other months are 0% change.

^(b) Reduces to < 20% change within 1,500 m of ponds.

Table 3.8-7 also summarizes changes in post-closure flows, which reflect long-term changes in runoff characteristics resulting from mining and reclamation activities. As part of mine closure, the runoff collection ponds will be decommissioned and the embankments will be breached to enable runoff to drain naturally to the receiving streams. The expected changes in flows just downstream of the pond locations are 20 to 24% for the Ambatovy area, and 8 to 12% for the Analamay area. The calculated percentage changes are the same for each month and season. Flows will gradually return to normal levels as vegetation continues to develop in the reclaimed areas.

The hydrologic modeling conducted to date provides estimates of monthly flow volumes and expected changes due to mine development. Land disturbance will also increase peak flows by generating larger runoff volumes and faster runoff times compared to baseline conditions. During operations, the runoff collection ponds will be operated to provide peak flow attenuation through short-term storage of storm water before release to downstream reaches. Changes in peak flows are expected to be similar to those for mean flows, with increases of up to about 20% immediately downstream of the embankments. These peak flows could be reduced by optimizing pond operations and by providing sufficient storage to capture large storm volumes. Following operations and reclamation, the collection ponds will be decommissioned and will no longer provide flow attenuation. As a result, peak flows will continue to be elevated following closure.

Streamflow at locations downstream of the ponds is the sum of pond releases and contributions from downstream tributary streams. As distance downstream and drainage area increase, the change in flow attributed to mine development decreases. Table 3.8-8 summarizes expected changes in January (i.e., wet season) flows at various distances downstream of the ponds. Table 3.8-9 summarizes changes in mean flows, as calculated on a monthly basis for the same locations. Pond outlet locations and sub-basins associated with various downstream distances are shown in Figure 3.8-1.

January flows reflect the greatest change in outflows from the ponds compared to baseline conditions (i.e., worst case conditions). In Year 4, mine development is most significant in the Ambatovy area. Changes in flow regimes are therefore greatest in the Ambotovy watersheds (e.g. Antsahalava, Sahamarirana, and Sahaviara basins), with increases of approximately 2% at 2 km and 1% at 5 km downstream of the ponds. By Year 10, mine development extends to the Analamay area and changes in flows are evident in all basins. Changes in January flows at 2 km downstream of the ponds range from 6 to 14% for the Ambatovy area and Sakalava watershed, and are 1 to 5% for the Torotorofotsy and Ankaja basins. Changes in flows in Years 15 and 20 reflect large areas of

active mining and overall disturbance. The increases in flows are around 20% within 1 km of the ponds for Year 15 and within 1.5 km for Year 20. At distances further downstream the changes are noticeably reduced. For example, the increase in flows is less than 5% at 3 km downstream in the Torotorofotsy and Sakalava watersheds. A similar percentage change is expected in the Sahaviara watershed for up to 5 km, and for up to 10 km for the remaining watersheds.

Expected changes in flows on a mean monthly basis are limited to 0 to 1% in Year 4 due to a relatively small percent of disturbed land. In Year 10, changes in mean flows in the Ambatovy area are less than 5% at 3 km downstream of the runoff collection ponds, and less than 5% immediately downstream of the ponds in the Analamay area. Mean flows in Year 15 in the Ambatovy area are comparable to flows in Year 10; however, continued development in the Analamay area results in mean flows about 7% greater than in Year 10 (Ankaja and Sakalava basins). In Year 20, changes in mean flows compared to baseline conditions are less than 5% within the following limits downstream of the ponds: 4 km in the Ambatovy area, 1 km in the Torotorofotsy and Sakalava basins, and about 8 km in the Ankaja basin.

For post-closure conditions, changes in flows are higher in the Ambatovy area than in the Analamay area due to a larger percentage of disturbed and reclaimed area. Post-closure flows in the Ambatovy area are 20 to 24% above baseline flows immediately downstream of the dam. The flow increase is reduced to less than 20% at about 1.5 km downstream, and to less than 10% at about 5 km downstream. In the Analamay area, the changes in flows are less than 10% at 2 km downstream of the pond locations.

Table 3.8-8 Changes in January Flows at Various Distances Downstream of Runoff Collection Ponds

| Scenario | Watershed | 0 (Pond Outlet) | | Distance Downstream of Pond (m) | | | | | | | | |
|--------------|---------------|---------------------------------------|--|---------------------------------|-------|-------|-------|-------|-------|-------|-------|--------|
| | | Baseline Flow (m ³ /month) | Development Flow (m ³ /month) | 500 | 1,000 | 1,500 | 2,000 | 3,000 | 5,000 | 6,500 | 7,500 | 10,000 |
| year 4 | Antsahalava | 668,879 | 685,881 | 2% | 2% | 2% | 2% | 2% | 1% | 1% | 1% | 1% |
| | Sahaviara | 252,860 | 268,052 | 5% | 4% | 3% | 3% | 2% | 1% | | 1% | |
| | Sahamarirana | 518,406 | 535,101 | 3% | 3% | 2% | 2% | 2% | 1% | | 1% | 1% |
| | Torotorofotsy | 610,633 | 610,633 | 0% | 0% | 0% | 0% | 0% | 0% | | | |
| | Sakalava | 529,968 | 529,968 | 0% | 0% | 0% | 0% | | 0% | | 0% | |
| | Ankaja | 866,529 | 893,272 | 3% | 2% | 2% | 2% | 2% | 1% | | 1% | 1% |
| year 10 | Antsahalava | 668,879 | 795,920 | 17% | 16% | 15% | 14% | 11% | 8% | 7% | 3% | 3% |
| | Sahaviara | 252,860 | 306,657 | 16% | 13% | 11% | 9% | 6% | 3% | | 2% | |
| | Sahamarirana | 518,406 | 619,342 | 17% | 16% | 13% | 10% | 9% | 6% | | 5% | 4% |
| | Torotorofotsy | 610,633 | 674,881 | 10% | 6% | 5% | 5% | 4% | 3% | | | |
| | Sakalava | 529,968 | 573,583 | 8% | 8% | 7% | 6% | | 3% | | 2% | |
| | Ankaja | 866,529 | 880,473 | 1% | 1% | 1% | 1% | 1% | 1% | | 1% | 0% |
| year 15 | Antsahalava | 668,879 | 815,159 | 20% | 19% | 18% | 17% | 13% | 9% | 8% | 4% | 4% |
| | Sahaviara | 252,860 | 319,328 | 20% | 16% | 13% | 12% | 7% | 4% | | 3% | |
| | Sahamarirana | 518,406 | 637,757 | 20% | 19% | 15% | 12% | 11% | 7% | | 6% | 5% |
| | Torotorofotsy | 610,633 | 666,743 | 8% | 5% | 4% | 4% | 3% | 2% | | | |
| | Sakalava | 529,968 | 639,005 | 20% | 19% | 18% | 14% | | 7% | | 5% | |
| | Ankaja | 866,529 | 973,874 | 11% | 9% | 9% | 8% | 7% | 6% | | 5% | 3% |
| year 20 | Antsahalava | 668,879 | 822,542 | 21% | 20% | 19% | 17% | 14% | 9% | 9% | 4% | 4% |
| | Sahaviara | 252,860 | 326,505 | 22% | 18% | 15% | 13% | 8% | 4% | | 3% | |
| | Sahamarirana | 518,406 | 644,823 | 22% | 20% | 16% | 13% | 11% | 8% | | 6% | 5% |
| | Torotorofotsy | 610,633 | 690,224 | 12% | 7% | 6% | 6% | 5% | 3% | | | |
| | Sakalava | 529,968 | 571,732 | 8% | 7% | 7% | 5% | | 3% | | 2% | |
| | Ankaja | 866,529 | 1,078,956 | 22% | 18% | 17% | 15% | 13% | 11% | | 10% | 5% |
| post-closure | Antsahalava | 668,879 | 836,555 | 23% | 22% | 20% | 19% | 15% | 10% | 9% | 5% | 4% |
| | Sahaviara | 252,860 | 318,674 | 20% | 16% | 13% | 11% | 7% | 4% | | 3% | |
| | Sahamarirana | 518,406 | 662,025 | 24% | 23% | 18% | 15% | 13% | 9% | | 7% | 5% |
| | Torotorofotsy | 610,633 | 666,348 | 8% | 5% | 4% | 4% | 3% | 2% | | | |
| | Sakalava | 529,968 | 597,511 | 12% | 12% | 11% | 9% | | 4% | | 3% | |
| | Ankaja | 866,529 | 975,069 | 11% | 9% | 9% | 8% | 7% | 6% | | 5% | 3% |

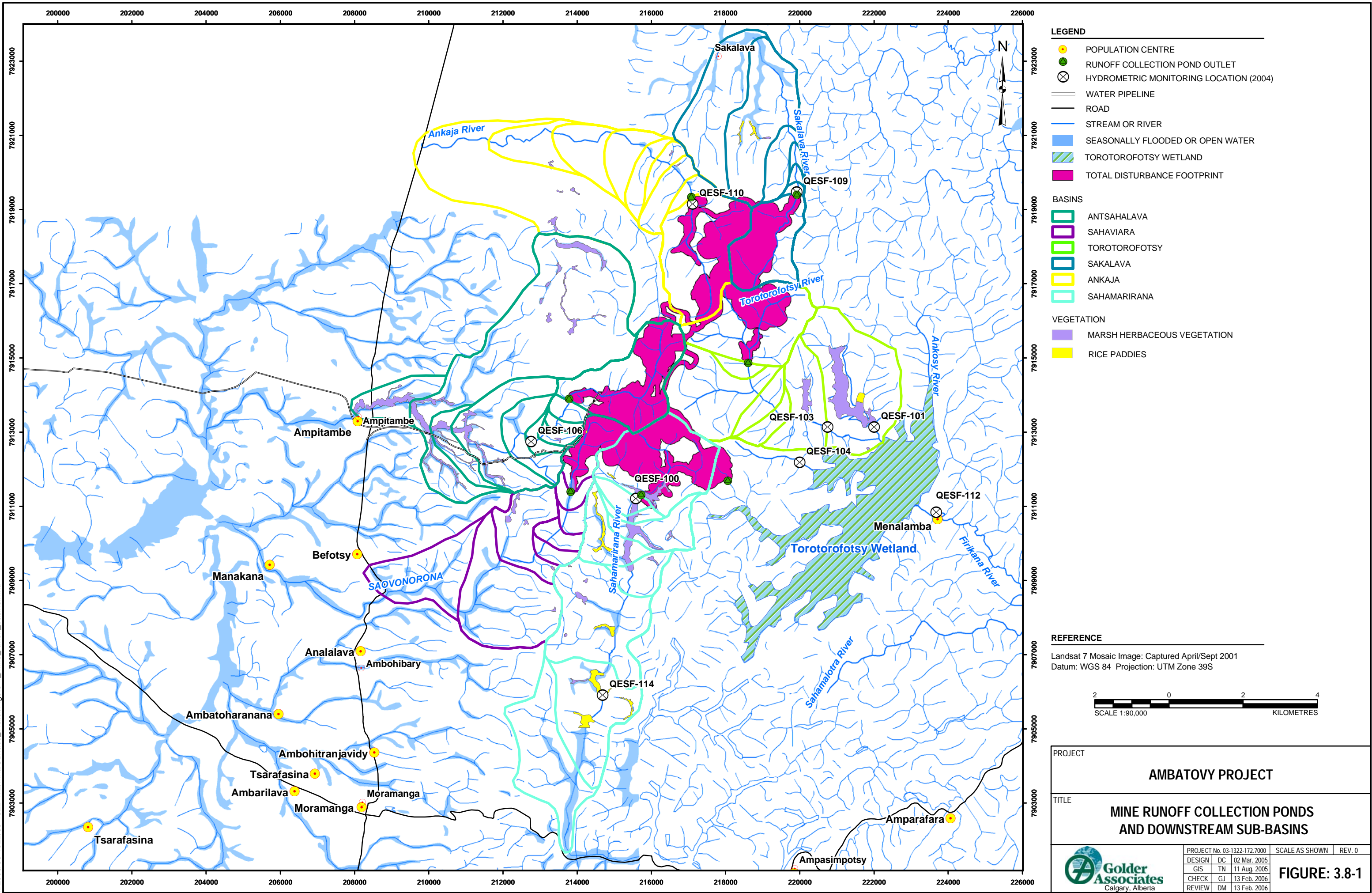
Notes: Blanks indicate location not included in hydrologic model.

Table 3.8-9 Changes in Mean Monthly Flows at Various Distances Downstream of Runoff Collection Ponds

| Scenario | Watershed | 0 (Pond Outlet) | | Distance Downstream of Pond (m) | | | | | | | | |
|--------------|---------------|---------------------------------------|--|---------------------------------|-------|-------|-------|-------|-------|-------|-------|--------|
| | | Baseline Flow (m ³ /month) | Development Flow (m ³ /month) | 500 | 1,000 | 1,500 | 2,000 | 3,000 | 5,000 | 6,500 | 7,500 | 10,000 |
| year 4 | Antsahalava | 302,493 | 303,910 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| | Sahaviara | 114,353 | 116,374 | 1% | 1% | 1% | 1% | 0% | 0% | | 0% | |
| | Sahamarirana | 234,444 | 235,835 | 1% | 0% | 0% | 0% | 0% | 0% | | 0% | 0% |
| | Torotorofotsy | 276,152 | 276,152 | 0% | 0% | 0% | 0% | 0% | 0% | | | |
| | Sakalava | 239,672 | 239,672 | 0% | 0% | 0% | 0% | | 0% | | 0% | |
| | Ankaja | 391,878 | 395,578 | 1% | 1% | 1% | 1% | 1% | 0% | | 0% | 0% |
| year 10 | Antsahalava | 302,493 | 335,040 | 10% | 9% | 9% | 8% | 6% | 4% | 4% | 2% | 2% |
| | Sahaviara | 114,353 | 128,619 | 9% | 8% | 6% | 5% | 3% | 2% | | 1% | |
| | Sahamarirana | 234,444 | 258,178 | 9% | 8% | 7% | 5% | 5% | 3% | | 2% | 2% |
| | Torotorofotsy | 276,152 | 290,982 | 5% | 3% | 3% | 2% | 2% | 1% | | | |
| | Sakalava | 239,672 | 248,855 | 4% | 4% | 3% | 3% | | 1% | | 1% | |
| | Ankaja | 391,878 | 393,040 | 0% | 0% | 0% | 0% | 0% | 0% | | 0% | 0% |
| year 15 | Antsahalava | 302,493 | 337,715 | 11% | 10% | 9% | 9% | 7% | 5% | 4% | 2% | 2% |
| | Sahaviara | 114,353 | 132,519 | 12% | 10% | 8% | 7% | 4% | 2% | | 2% | |
| | Sahamarirana | 234,444 | 264,951 | 11% | 11% | 8% | 7% | 6% | 4% | | 3% | 3% |
| | Torotorofotsy | 276,152 | 288,298 | 4% | 2% | 2% | 2% | 2% | 1% | | | |
| | Sakalava | 239,672 | 266,591 | 11% | 10% | 10% | 8% | | 4% | | 3% | |
| | Ankaja | 391,878 | 421,990 | 7% | 6% | 5% | 5% | 4% | 4% | | 3% | 2% |
| year 20 | Antsahalava | 302,493 | 339,663 | 11% | 11% | 10% | 9% | 7% | 5% | 5% | 2% | 2% |
| | Sahaviara | 114,353 | 134,929 | 14% | 11% | 9% | 8% | 5% | 2% | | 2% | |
| | Sahamarirana | 234,444 | 268,082 | 13% | 12% | 9% | 8% | 7% | 4% | | 3% | 3% |
| | Torotorofotsy | 276,152 | 299,909 | 8% | 5% | 4% | 4% | 3% | 2% | | | |
| | Sakalava | 239,672 | 245,858 | 2% | 2% | 2% | 2% | 1% | 1% | | 1% | 1% |
| | Ankaja | 391,878 | 451,341 | 14% | 11% | 11% | 9% | 8% | 7% | | 6% | 3% |
| post-closure | Antsahalava | 302,493 | 378,323 | 23% | 22% | 20% | 19% | 15% | 10% | 9% | 5% | 4% |
| | Sahaviara | 114,353 | 144,117 | 20% | 16% | 13% | 11% | 7% | 4% | | 3% | |
| | Sahamarirana | 234,444 | 299,394 | 24% | 23% | 18% | 15% | 13% | 9% | | 7% | 5% |
| | Torotorofotsy | 276,152 | 301,349 | 8% | 5% | 4% | 4% | 3% | 2% | | | |
| | Sakalava | 239,672 | 270,218 | 12% | 12% | 11% | 9% | | 4% | | 3% | |
| | Ankaja | 391,878 | 440,964 | 11% | 9% | 9% | 8% | 7% | 6% | | 5% | 3% |

Notes: Blanks indicate location not included in hydrologic model.

I:/2003/03-1322/03-1322-172/mxd/Surface_Water/Fig3.8-1_mine_runoff_basins.mxd



Water Levels and Velocities

Changes in water levels and velocities were estimated at five locations for operational and post-closure conditions using predicted flows at each location. The locations coincide with hydrometric monitoring stations where channel cross-section surveys, rating curves and water level datums are available. The expected changes in hydraulic characteristics for January flows are shown in Tables 3.8-10 and 3.8-11.

Increases in average depth during operations at the five sites range from 1 to 13% (1 to 8 cm), while increases in average velocity range from 0 to 20% (0 to 0.2 m/s). The hydrometric stations QESF-100, 109, and 110 stations are located approximately 500 m downstream of the collection ponds in their respective basins. QESF-106 is about 2 km downstream of the Ambatovy North RCP and QESF-114 is about 5 km downstream of the Ambatovy South RCP.

Influence of Groundwater on Surface Water Flows

Mining activities are expected to reduce infiltration to groundwater in disturbed areas, as well as result in dewatering of the surrounding fractured bedrock where the mine pits are developed. Dewatering of the mine pit will reduce the groundwater flux toward the receiving streams and will reduce the amount of groundwater that daylights at downstream locations. As discussed in Volume B, Section 3.7, groundwater contributions to baseflow are expected to be reduced by 7% in the upper river watersheds that feed the Mokaranana and Torotorofotsy wetlands. Changes in groundwater contribution have not been explicitly accounted for in the hydrologic model; however, where acceptable from a water quality perspective, pits can be dewatered to the runoff collection ponds, and therefore any downstream groundwater deficits can be offset by releasing greater volumes of excess surface runoff.

Table 3.8.10 Changes in January Water Depths and Velocities at Monitoring Locations^(a) – Operation Year 20

| Basin | Station | Baseline | | | | | Operation | | | | | Operation - 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) |
| Sahamarirana | QESF-100 | 0.22 | 10.39 | 1.14 | 1.70 | 0.02 | 0.27 | 11.07 | 1.14 | 1.78 | 0.02 | 23% | 7% | 0% | 5% | 0% |
| Sahamarirana | QESF-114 | 0.63 | 2.77 | 0.92 | 1.18 | 0.23 | 0.67 | 2.84 | 0.95 | 1.20 | 0.24 | 6% | 3% | 3% | 2% | 4% |
| Antsahalava | QESF-106 | 0.33 | 1.06 | 0.39 | 0.52 | 0.31 | 0.39 | 1.19 | 0.44 | 0.57 | 0.33 | 18% | 12% | 13% | 10% | 6% |
| Ankaja | QESF-110 | 0.35 | 6.27 | 0.96 | 1.55 | 0.06 | 0.43 | 6.31 | 0.97 | 1.57 | 0.07 | 23% | 1% | 1% | 1% | 17% |
| Sakalava | QESF-109 | 0.21 | 1.16 | 0.20 | 0.37 | 0.18 | 0.22 | 1.16 | 0.20 | 0.37 | 0.19 | 5% | 0% | 0% | 0% | 6% |

^(a) Flow characteristics at hydrometric monitoring locations.

Table 3.8.11 Changes in January Water Depths and Velocities at Monitoring Locations^(a) –Closure

| 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) |
| Sahamarirana | QESF-100 | 0.22 | 10.39 | 1.14 | 1.70 | 0.02 | 0.27 | 10.76 | 1.18 | 1.74 | 0.03 | 23% | 4% | 4% | 2% | 50% |
| Sahamarirana | QESF-114 | 0.63 | 2.77 | 0.92 | 1.18 | 0.23 | 0.68 | 2.87 | 0.96 | 1.21 | 0.24 | 8% | 4% | 4% | 3% | 4% |
| Antsahalava | QESF-106 | 0.33 | 1.06 | 0.39 | 0.52 | 0.31 | 0.39 | 1.19 | 0.44 | 0.57 | 0.33 | 18% | 12% | 13% | 10% | 6% |
| Ankaja | QESF-110 | 0.35 | 6.27 | 0.96 | 1.55 | 0.06 | 0.39 | 6.29 | 0.97 | 1.56 | 0.06 | 11% | 0% | 1% | 1% | 0% |
| Sakalava | QESF-109 | 0.21 | 1.16 | 0.20 | 0.37 | 0.18 | 0.23 | 1.21 | 0.20 | 0.38 | 0.19 | 10% | 4% | 0% | 3% | 6% |

^(a) Flow characteristics at hydrometric monitoring locations.

Mangoro River Pipeline

The Mangoro River will be the primary supply for mine water requirements. In the wet season, withdrawals from the Mangoro River may be significantly reduced if mine water requirements can be largely satisfied by excess local (mine site) runoff. As shown in Table 3.8-12, mine water requirements of approximately 1,000 m³/h (0.28 m³/s) represent less than 0.3% of the mean annual flow in the Mangoro River, and less than 1.5% of the flow for dry conditions. These dry conditions are based on minimum daily flows, but can also be used to characterize drought conditions where low flows are maintained over a prolonged period. In terms of maximum daily flows, the mine withdrawal would represent less than 0.1% of the available Mangoro River water.

Table 3.8.12 Change in Mangoro River Flow due to Mine Water Withdrawal

| Flow | Mangoro River Flow (m³/s) | Withdrawal for Mine Supply (m³/s) | Withdrawal |
|---------------------------|---|---|-------------------|
| Driest month (Oct) | 22.5 | 0.28 | 1.2% |
| Annual | 88.9 | 0.28 | 0.3% |
| Minimum daily flow: 2-yr | 23.3 | 0.28 | 1.2% |
| Minimum daily flow: 5-yr | 21.3 | 0.28 | 1.3% |
| Minimum daily flow: 10-yr | 20.2 | 0.28 | 1.4% |
| Maximum daily flow: 2-yr | 440 | 0.28 | <0.1% |
| Maximum daily flow: 5-yr | 810 | 0.28 | <0.1% |
| Maximum daily flow: 10-yr | 1,210 | 0.28 | <0.1% |

The proposed Mangoro River pipeline is about 23 km long and crosses seven small- to moderate-sized streams between the river and the mine site. Construction and operation of the pipeline corridor and associated access road may result in local increases in runoff due to land disturbance, but these changes are not expected to be measurable in receiving water bodies. During construction, there may be short-term changes in flow velocities and depths where the pipeline is buried at watercourse crossing locations. No changes during operations or post-closure are expected.

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

Mine Site

The lateritic soils around the mine site are highly weathered and erodible. Soil disturbance, excavation, and removal of vegetation associated with mining activities are expected to result in high suspended sediment concentrations in runoff from the area, particularly during large wet season rainfall events. Erosion control measures including slope stabilization, sediment fences and diversion ditches will be used to manage sediment generation and transport. Water management facilities have also been designed to capture all runoff in a series of collection and clarification ponds before discharge to the environment. The ponds have been sized to retain the 1:10 year 24-hour storm and to settle suspended sediments to meet the World Bank water quality guideline of 50 mg/L associated with flows from this design storm.

Natural sedimentation will occur in the collection ponds and, under normal conditions, is expected to produce outflow sediment concentrations below the 50 mg/L guideline. For larger events up to the design storm, flocculant will be required to increase settling rates and the amount of sediment removed from runoff in order to meet the effluent guideline. Flocculant will be added at the collection pond and additional settling will occur in the downstream clarification pond. The clarification ponds are sized based on tests which indicate that flocculation produces a 10-fold decrease in settling time.

Storm events exceeding the 1:10 year 24-hour storm will result in large flow volumes and high flow rates. The retention times provided by the ponds under these conditions may be less than the natural and flocculated settling rates, resulting in suspended sediment transport to receiving streams at concentrations exceeding 50 mg/L. Inflowing suspended sediment concentrations, from the mine area as well as from natural areas, are expected to be high under these conditions due to high erosion and runoff. This was an area of concern highlighted during consultation sessions during September 2005, where adequacy of proposed mitigations was discussed (Volume A, Section 6). In recognition of this concern and of sensitivities in the downstream environment, additional sediment modeling is being conducted to help quantify the levels of sediment leaving the ponds for events in excess of the 1:10 year 24-hour storm, with particular attention to the Torotorofotsy area. These results will be provided in an addendum to the EA, once available.

Mangoro River Pipeline

During construction of the Mangoro pipeline, some localized increases in sediment levels in receiving streams are expected, despite the use of erosion control measures. Prior to reclamation, sediment is expected to be generated from the pipeline corridor and at watercourse crossings. Best management practices will be used to reduce sediment levels as much as possible. Examples of typical practices are provided in Volume C, Section 3.8. With the use of best management practices along the route and specific erosion control at watercourse crossing locations (see Volume C, Section 3.8), no significant changes to sediment concentrations in receiving water bodies are expected during operations or closure.

3.8.5.7 Results for Key Question H-3: What Effect Will the Mine Have on Torotorofotsy Wetlands Hydrology and Sediment Loading?

The Torotorofotsy River is the primary inflow to the Torotorofotsy wetlands and represents about 15 km² (25%) of the total (60 km²) drainage area for the wetlands. The Anamalay ore body is located in the upper reaches of the Torotorofotsy River watershed. In around Year 15 of operations, a small runoff collection pond will be constructed adjacent to the Ambatovy Southeast Backfill. This pond has a small drainage area of about 20 ha, the majority of which is reclaimed area. The remainder of the contributing Torotorofotsy wetlands watershed is unaffected by mine development.

Wet season flows in the Torotorofotsy River, at the inlet to the wetlands, are expected to increase by up to 3% during mine operations due to changes in upper basin runoff characteristics. As discussed in Volume B, Section 3.7, mine dewatering is also expected to result in about a 7% reduction in groundwater contribution in the upper basins. The local 3% increase in surface flows represents less than 1% of the total wetlands inflow. No changes in flows are expected in the dry season during operations. For post-closure conditions, Torotorofotsy River flows in both the wet and dry seasons are expected to increase by about 2% over baseline conditions due to long-term changes in runoff characteristics on the mine site. The expected post-closure increase in flow to the wetlands from the entire drainage area is less than 1%.

Under normal operating conditions, water and sediment from the upper Torotorofotsy River basin will be managed by the Anamalay South mine runoff collection and clarification ponds. Under normal operating conditions, the discharge from this pond is expected to meet the 50 mg/L suspended sediment guideline for the 1:10 year event. A modeling exercise is being undertaken to

help quantify and understand the suspended solids concentrations associated with more extreme storm events.

3.8.6 Impact Analysis

3.8.6.1 Residual Impacts

During operations, the highest changes in streamflows are expected to occur toward the end of the operational phase when active mining and stockpile areas, as well as reclaimed areas, are greatest. The largest changes in flows occur in January (worst case) and, for most basins in Year 20, the increases are expected to be 15 to 20% above baseline conditions for the first 1.5 km downstream of the embankments (increases in the Torotorofotsy and Sakalava watersheds are less at about 7%). For mean conditions assessed on a monthly basis, the changes in flows are on the order of 10% at 1.5 km downstream of the ponds. Based on the data provided in Table 3.8-8, these impact magnitudes are considered moderate for worst case conditions and low for mean flows. In general, increases in January flows will be 5 to 10% at distances 5 to 7.5 km downstream of the ponds (i.e., low impact), and are expected to be less than 5% (i.e., negligible impact) beyond the 7.5 km point. January flow increases within the Torotorofotsy and Sakalava drainages are slightly less with low impacts expected between 1 and 3 km downstream of the collection pond, followed by negligible changes beyond that. In terms of mean flows, the impact magnitudes are less than 10% (low environmental consequence) beyond 1.5 km and less than 5% (negligible environmental consequence) beyond the following limits: 3 km for the Sahaviara basin, 5 km for the Antsahalava and Sahamarirana basins, 1 km for the Torotorofotsy basin, 500 m for the Sakalava basin, and 8 km for the Ankaja basin.

For post-closure conditions (all months), increases in flows of 10 to 22% are expected in the Ambatovy area (Antsahalava, Sahaviara, and Sahamarirana watersheds) up to a distance 5 km downstream of the collection ponds. These moderate impacts are reduced to negligible impacts at about 7.5 km from the ponds. Impacts in the Analamay area (Sakalava and Ankaja watersheds) are considered moderate immediately downstream of the ponds (12% increase), low by 1.5 km, and negligible at about 5 km. Changes in flows in the Torotorofotsy River are considered low impact for the first 1.5 km downstream of the pond and negligible beyond that point.

Changes in water levels were assessed at five locations around the mine site. Based on relatively small changes at these locations, effects within the local study area are also expected to be small and therefore result in a low environmental consequence.

The withdrawal of Mangoro River water for mine supply is expected to have a negligible impact on flows and water levels in the river for average and minimum flow conditions.

Sediment yield during construction and operations is expected to be high due to development and mining activities. However, transport of the sediment, to receiving streams will be controlled by erosion and sediment control measures as well as sedimentation within the collection and clarification ponds. For operating conditions up to the 1:10 year design event, sediment concentrations will be below the 50 mg/L guideline. These impacts are low to moderate in magnitude and, due to the local extent and medium term duration, are considered of low environmental consequence.

For storm events greater than the design event, sediment levels entering the receiving streams may exceed the 50 mg/L criteria. The elevated concentrations, however, will be diluted by downstream flows. Impacts could be high in terms of magnitude at the pond outlets. Based on the local extent, short-term duration, and low occurrence, the environmental consequence is considered moderate. Due to the sensitive nature of downstream receiving environments, additional sediment modeling is being undertaken to estimate and understand the implications of sediment concentrations that could be released from the ponds during large storm events. These results will be provided in an addendum to the EA, once available.

The runoff collection pond in the headwaters of the Torotorofotsy River will be operated to minimize changes in flows to the Torotorofotsy wetlands. Increases in flows in the Torotorofotsy River at the inlet to the wetlands will be about 3% during operations and about 2% for post-closure conditions. These changes in flows are considered negligible. For normal operating conditions, sediment concentrations released to the Torotorofotsy River from the mine area will be limited to the 50 mg/L design guideline. This is expected to result in a negligible to low change in overall sediment load to the wetlands. Impacts associated with extreme events have not been quantitatively assessed and are currently under investigation for various extreme storm events.

Residual impacts are presented in Table 3.8-13.

Table 3.8-13 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 | wet season: moderate to 5 km; low to negligible beyond 5 km dry season: negligible mean: moderate to 1.5 km; low to negligible beyond 1.5 km | local local local | medium-term | yes | high (average conditions) | wet season: low (to 5 km); low to negligible (beyond 5 km) dry season: negligible mean: low (to 1.5 km); low to negligible (beyond 1.5 km) |
| closure | negative | Ambatovy (south) basins: moderate to 5 km; low to negligible beyond 5 km Analamay (north) basins: moderate (to 1.5 km); Low (1.5 to 5 km); negligible (beyond 5 km) | local local | long-term | no | high (average conditions) | Ambatovy (south) basins: low (to 5 km); Low to negligible (beyond 5 km) Analamay (north) basins low to negligible (beyond 1.5 km) |
| Issue: Changes in Sediment Levels in Receiving Water Bodies^(a) | | | | | | | |
| construction/ operations | negative | low to moderate | local | short-term | yes | | low |
| operations | negative | for design conditions: low to moderate for extreme events: moderate to high | local | medium-term short-term | yes | high (average conditions) low | low moderate |
| closure | negative | negligible to low | local | long-term | no | high (average conditions) | low |
| Issue: Changes in Torotorofotsy Wetlands Hydrology and Sediment Levels | | | | | | | |
| construction/ operations | negative | flows: negligible sediment: low for typical conditions; moderate to high for extreme events ^(b) | local | medium-term medium-term short-term | yes | high (average conditions) high (average conditions) low | negligible (flows) to low (sediment) for typical conditions negligible to moderate for extreme events |
| closure | negative | flows: negligible sediment: low | local | long-term | no | high (average conditions) | negligible to low |

^(a) Changes in sediment levels immediately downstream of the runoff collection ponds; sediment levels in receiving streams will decrease with increasing distance downstream due to dilution from tributary water.

^(b) High magnitude change is based on worst-case assumption; data collection and modeling are currently being conducted to improve understanding of sediment levels under extreme events.

3.8.6.2 Prediction Confidence

With the exception of evapotranspiration, regional climate variables affecting baseline hydrology are well understood. Local climate data from the mine site is limited and can result in uncertainty in understanding the hydrology in terms of rainfall response and runoff generation. To improve confidence, larger climate data bases from nearby locations have also been used to help characterize the local hydrology. Due to the complexity of the groundwater regime, the interaction between surface water and groundwater in the project area is not well understood (Volume I, Appendix 7.1).

The impact ratings are based on a hydrologic model that assesses average monthly conditions based on reasonable estimates of annual rainfall and runoff. The prediction confidence associated with model flows is considered medium. Management of pond releases and diversions is key in terms of prediction confidence.

The prediction confidence associated with sediment concentrations is considered high for normal flow conditions up to the design flow. Despite the uncertainties related to extreme events greater than the design storm, the prediction confidence (moderate environmental consequence) is considered moderate to high due to the short-term duration and local extent of the occurrence.

3.8.6.3 Monitoring

There will be continued climatological and streamflow monitoring within the affected basins to help define flow variability. The data will be used to ensure that pond operational guidelines meet downstream needs and minimize impacts. The pond releases and downstream flows will be routinely monitored. In addition, regular contact with downstream users will be made to solicit feedback on the acceptability and availability of flows.

Throughout the project, monitoring of the effectiveness of erosion control measures, slope stability, and reclamation success will be conducted. Sediment and other key water quality parameters released from the collection ponds will be monitored to ensure compliance with water quality criteria. Inflowing sediment concentrations will also be monitored to optimize flocculant dosages and to ensure adequate settling within the clarification ponds.

3.8.7 Conclusions

During construction, operations and post-closure, the mine area will have a negligible to low environmental consequence for wet season streamflows at downstream locations. The consequence will be negligible for dry season flows.

For the operation and post-closure conditions, the mine will have a negligible to low environmental consequence for sediment concentrations in receiving streams. For extreme flow conditions during operations, the environmental consequence may be moderate.

The mine is expected to have a negligible to low environmental consequence related to flows and sediment concentrations in the Torotorofotsy Wetlands.

3.9 WATER QUALITY

3.9.1 Introduction

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

The project will include the development of a nickel laterite mine for two ore bodies, referred to as the Ambatovy and Analamay areas. Development of the mine will involve varying degrees of land disturbance, such as removal of vegetation, excavation and ground compaction. The mine will also include the construction of roads, buildings, parking and storage areas, waste dumps, and an ore preparation facility, which will include the preparation plant and water holding pond or tank. These disturbances will result in increased rates of runoff from the area until reclamation and re-vegetation activities are complete. The increased runoff will likely increase erosion and transport additional sediment into downstream watercourses. Changes in suspended sediment concentration due to potential increases in erosion are addressed in Section 3.8 of this volume (Hydrology).

During operations, the water quality of runoff that originates from different land types within the mine area may be different than the water quality of runoff during baseline conditions. All runoff from the site will be controlled. The majority of the runoff from the mine area will be routed to collection and clarification ponds and then released to downstream watercourses and water bodies. These releases have the potential to affect the water quality of the receiving downstream waters. Any runoff that is not routed to the ponds will be diverted to the ore preparation plant or slurry pipeline that transports mined ore to the process plant, as described in Volumes C (slurry pipeline) and D (process plant).

The mine development and operations can also cause changes in sediment quality. Increases in the concentration of substances (e.g., metals and organics) in the water column may enhance adsorption of these substances to 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 and water bodies.

3.9.2 Study Area

The Local Study Area (LSA) for water quality is the same as the hydrology study area presented in Volume A, Figure 7.2.1. The area covers the likely spatial extent of mine development and effects on water and sediment quality. The LSA includes the following areas:

- six main basins draining the mine (i.e., Antslahalava, Sahaviara, Torotorofotsy, Sakalava, Sahamarirana and Ankaja rivers);
- location of the water intake pipe on the Mangoro River; and
- the Torotorofotsy Wetlands.

3.9.3 Baseline Summary

3.9.3.1 Water Quality

Based on water quality sampling conducted during both the dry and wet seasons in 2004, water quality near the mine area has pH values of 6.8 to 7.2, and dissolved oxygen values generally near saturation. Water temperatures typically range from 18 to 24°C, although higher temperatures have been observed in some of the watercourses and water bodies.

Hardness values for surface waters near the mine area range from very soft to moderately soft. Based on observed alkalinity results, some water bodies appear to be sensitive to acidification. Nutrient levels are generally low for nitrogen substances, including nitrate, nitrite, total kjeldahl nitrogen (TKN) and ammonia, and typically below detection limits for total phosphate.

In general, there are no clear seasonal patterns for most of the water quality substances measured in the mine area. In addition, with few exceptions, there is no clear spatial variability in water quality. The exceptions include magnesium and chromium during the dry season, which appear to have higher concentrations at stations downstream of the Ambatovy and Analamay ore bodies relative to stations located further away from the ore bodies.

Based on the Madagascar classification system for surface waters (Table 3.9-1), most watercourses and water bodies near the mine site are assigned to “Class A” (i.e., water is suitable for multiples uses). No stations were classified as excessively contaminated (Class HC) in the mine area. Concentrations of lead and nickel, in the dry season and arsenic in the wet season were higher than the World Health Organization (WHO 2004) drinking water quality guideline values.

Table 3.9-1 Madagascar Classification System for Surface Water Quality

| Factors | Class A | Class B | Class C | Unclassifiable (Class HC) |
|--|--------------------------------------|---|------------------------------------|---|
| Classification definition | Good quality: multiple uses possible | Moderate quality: non-contact recreation allowed; swimming may not be allowed | Poor quality: swimming not allowed | Excessive contamination: no use possible except for boating |
| Biological Factors | | | | |
| dissolved oxygen (mg/L) | DO \geq 5 | 3 < DO < 5 | 2 < DO \leq 3 | DO < 2 |
| 5-day biological oxygen demand (BOD ₅) | BOD ₅ \leq 5 | 5 < BOD ₅ \leq 20 | 20 < BOD ₅ \leq 70 | BOD ₅ > 70 |
| chemical oxygen demand (COD) | COD \leq 20 | 20 < COD \leq 50 | 50 < COD \leq 100 | COD > 100 |
| presence of pathogenic bacteria | no | no | no | yes |
| Physical and Chemical Factors | | | | |
| colour (TCU) | colour < 20 | 20 \leq colour \leq 30 | colour < 30 | n/a |
| water temperature (°C) | temperature < 25 | 25 \leq temperature < 30 | 30 \leq temperature < 35 | temperature > 35 |
| pH | 6.0 \leq pH \leq 8.5 | 5.5 < pH < 6.0 or 8.5 < pH 9.5 | pH \leq 5.5 or pH \geq 9.5 | N/A |
| total suspended solids (TSS) (mg/L) | TSS < 30 | 30 \leq TSS < 60 | 60 \leq TSS < 100 | TSS > 100 |
| conductivity (μ S/cm) | conductivity \leq 250 | 250 < conductivity \leq 500 | 500 < conductivity \leq 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 Environmental Protection Agency [EPA] 2004) were used to screen baseline water quality. Where CCME and EPA guidelines for aquatic life differed, the most stringent guideline from both jurisdictions was compared to observed water quality data. South African Aquatic Ecosystem Guidelines (Department of Forest and Water Affairs 1996) were used to compare to assessment results because they are the closest regionally approved set of water quality guidelines.

Screening results show that several metals including aluminium, arsenic, chromium, copper, iron, lead, mercury, nickel and zinc occasionally had concentrations exceeding either EPA or CCME aquatic life guideline values. However, because the EPA or CCME guidelines do not take into account local ecological conditions in Madagascar, exceedances of these guidelines should be treated with caution. Indeed, it is not uncommon for baseline substance concentrations to be higher than guideline values even in jurisdictions where they

have been derived, due to local climatic, geological and hydrogeochemical characteristics and the adaptation of site-specific aquatic species.

3.9.3.2 Sediment Quality

Stream bed sediment in the mine area ranged from predominantly fines to predominantly coarse material. Differences in the physical characteristics of sediments are manifested as differences in key chemical characteristics of sediment, including organic carbon, nutrients and metals. However, due to the limited sediment quality sampling undertaken so far, it is not possible to identify clear spatial trends in sediment characteristics within the mine area.

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). Because guidelines from other jurisdictions do not take into account local ecological conditions, guideline exceedances should be treated with caution. These international sediment quality guidelines are available only for a few metals, including arsenic, cadmium, copper, lead, mercury, nickel and zinc. Of the metals with sediment guidelines, only two, copper and nickel, were above the corresponding international guidelines.

Additional details concerning baseline conditions are provided in Volume I, Section 9.1.

3.9.4 Issue Scoping

Surface water concerns of stakeholders and regulators are focused on potential changes for water users and ecological processes (Volume A, Section 6). Downstream water users and aquatic life may be adversely affected by changes in water and sediment quality associated with construction, operation, and closure activities of the project. In the watersheds 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 mine area could potentially affect water and sediment quality of nearby surface watercourses and water bodies:

- site preparation and clearing;
- air emissions from ore preparation plant, mine equipment and vehicles;

- diversion and disruption of natural drainages;
- metal leaching from waste rock and ore stock piles;
- seepage from the mine area;
- runoff releases from the collection and clarification ponds used to manage water from the mine areas;
- accidental releases and spills; and
- site closure and reclamation activities.

The linkages between project activities and effects on water and sediment quality are given in Volume H, Appendix 9. Potential water and sediment quality effects can occur during all phases of the project, including construction, operations and post-closure.

The key question for water and sediment quality is:

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

3.9.5 Impact Assessment

The proposed mine area is located within a drainage divide of six water basins, including the Antsahalava, Sahaviara, Torotorofotsy, Sakalava, Sahamarirana and Ankaja rivers. The Antsahalava, Sahaviara and Sahamarirana basins drain the Ambatovy ore area, while the Torotorofotsy, Sakalava and Ankaja basins drain the Analamay ore area.

Collection and clarification ponds will be located in each of the six basins to collect and reduce sediments carried by runoff from areas affected by the mine. In each basin, water will be routed through the collection pond and then a clarification pond before it is released to the receiving watercourses and water bodies. The runoff may originate from undisturbed areas, mined areas, waste stock pile areas or other disturbed areas (i.e., roads and buildings) within the mine area. However, highly affected active pit sump water will be preferentially routed to the ore preparation plant. The sub-basins associated with various downstream distances are shown in the Hydrology Section (Volume B, Figure 3.8-1).

The following impact pathways have been assessed relative to changes in water and sediment quality:

Water Removal from the Mangoro River

Water will be pumped from the Mangoro River for mine water requirements. Construction of the intake will include erosion control measures to minimize the amount of sediment entering the Mangoro River. The hydrology assessment predicted a maximum reduction of 0.5% to annual average flows and 1.4% to the lowest 10-year flow at the intake pipe in the Mangoro River. These predicted changes in flow and the erosion control measures will result in negligible changes in water and sediment quality in the Mangoro River.

Air Emissions Impact on Surface Water Quality

Nitrogen and sulphur dioxides will be released through air emissions from the combustion of fossil fuels within the mine area. These types of air emissions have the potential to cause acidification (lowering of the pH) in natural ponds located within the undisturbed area of the mine. However, there is insufficient water quality data from these natural ponds to complete an assessment of acidification potential. Additional monitoring of these ponds, including on-site azonal vegetation protection areas, will be completed before construction.

Acidification of the receiving watercourses around the mine is not expected to occur based on baseline pH values (6.8 to 7.2) and predicted alkalinity (21 to 45 mg/L as CaCO_3). Therefore, acidification of receiving watercourses was not assessed further.

Seepage

The water quality of seepages from the mine areas, during operations and post-closure, has the potential to be different compared to baseline groundwater concentrations. However, the amount of seepages is expected to be minimal, as described in the Hydrogeology Section 3.7 (Volume B). Based on the current understanding of the groundwater system, seepages are not expected to affect surface water and sediment quality in downstream receiving watercourses and water bodies.

Accidental Releases or Spills

Accidental releases or spills have the potential to affect water and sediment quality and impair downstream water uses depending on the type of material, magnitude, duration, weather conditions and location of the spill or release. Although no accidental releases or spills were assessed in the water quality section, mitigations have been identified to reduce and minimize the effects of these events in Section 3.9.5.4. Furthermore, environmental management systems will be developed and implemented to minimize potential occurrence, characterize water and sediment quality changes, and reduce likely effects, if such an event should occur.

Storm Events

Substance releases during storm events have the potential to change water quality downstream of the mine areas. Increased erosion from high runoff may increase suspended solids and bed sediments in downstream watercourses and water bodies. With the exception of TSS, water quality constituents will be substantially diluted due to the large volumes of water. This dilution should cause concentrations of most water quality constituents to decrease. Additional fieldwork and assessment are being conducted to better quantify the effects of increased sediments due to large storm events.

Release of Water from Ponds during Operations

The collection and clarification ponds will collect runoff from six main basins in the mine area. A portion of land in each of the six basin areas will remain undisturbed and its corresponding runoff will retain baseline water quality characteristics. However, the water quality of runoff collected from the disturbed areas has the potential to be different compared to baseline concentrations. These areas will include: mined areas, stock pile and waste areas, reclaimed areas, pond areas and other disturbed areas (i.e., for roads, buildings and other mine-related facilities). This impact pathway was assessed using a mass balance model, as described below under the impact assessment methods (Section 3.9.5.1).

Release of Water from Ponds during Post-Closure

During post-closure, water quality of runoff from the reclaimed areas may remain different than baseline water quality. Therefore, the runoff could potentially continue to affect water quality downstream of the mine area.

Sediment

Changes in water quality, particularly for metals and nutrients that tend to adsorbed to sediment particles, may cause changes in sediment quality in receiving watercourses and water bodies. This impact pathway was assessed further using a sediment quality model, as described below under impact assessment methods (Section 3.9.5.1).

3.9.5.1 Assessment Methods

The assessment of water and sediment quality was an iterative process, with the incorporation of evolving mitigations. This iterative assessment process continued until predicted water and sediment quality values due to mine-related activities were below applicable threshold values for human, flora, fauna and aquatic life health. The assessment of mine-related effects of water and sediment quality on biological receptors is described in Volume B. The human, flora, fauna and aquatic life health assessments were based on predicted water and sediment quality described below in Section 3.9.5.4.

In the mass balance model, water quality concentrations were calculated at the same set of assessment nodes and scenario snapshots for which flows were predicted (Volume B, Section 3.8). For each of the six basins, water quality was predicted at several assessment nodes located from 0 to 10,000 metres downstream of the clarification ponds. These assessment nodes provide representative water and sediment quality conditions within the LSA under baseline, operations, and post-closure conditions. The assessment nodes also considered locations where baseline and predicted flows were available, as described in the Hydrology Section (Volume B, Section 3.8).

For each water basin, the assessment was completed on a monthly basis for six scenario snapshots. The scenarios are baseline, four operational time snapshots (Year 4, Year 10, Year 15 and Year 20) and post-closure. These scenario snapshots are consistent with the scenarios used in the Hydrology Section (Volume B, Section 3.8).

Water Quality

A mass balance model was used to predict changes in water quality due to releases of water from the clarification ponds to the receiving environment during operations and post-closure. Baseline water quality was based on measured data. Changes in total suspended solids concentrations are addressed specifically in Volume I, Appendix 9.2.

Assumptions for water quality modeling are based on current project design. The environmental team has worked closely with the engineering design team to develop reasonable assumptions of sufficient detail to enable monthly water quality simulation. Some aspects of engineering and therefore specific assumptions may change as a result of detailed engineering, however, mitigation will ensure that any impacts on water or sediment quality will be within the levels presented in this assessment.

Modelling assumptions based on the current design included:

- fully mixed conditions;
- conservative behaviour of all substances (i.e., no attenuation in the clarification ponds and no geochemical transformations in the surface waters);
- a maximum of 25% of any one of the mining pits would be exposed at any time;
- suspended solids from the ponds will be less than 50 mg/L up to a 1 in 10 year storm;
- runoff and receiving waters concentrations as outlined in Table 3.9-2;
- vegetation cover over reclaimed areas to prevent runoff water from coming into contact with mine or waste material;
- runoff quality from the 'capped' reclaimed areas will be equivalent to baseline runoff quality; and
- natural, undisturbed water quality adequately represents baseline conditions.

Flows from each land type within the mine and at each assessment node were provided by the hydrology component (Volume B Section 3.8). Diversions of runoff water from the active mine, waste and ore storage areas were required during the mine operations phase to reduce substance loadings to the clarification ponds in the three basins in the Analamay mining area. The following operating rules were assumed for diversions of runoff in the modelled scenarios:

- The primary source of water for the ore preparation plant is the Mangoro River.
- If required, flows from active mine, waste and ore storage areas would be transferred directly to the ore preparation plant rather than to one of the six clarification ponds.
- If flows into receiving watercourses need to be further reduced after diverting all runoff from active mine, waste and ore storage areas, the

additional downstream flow reduction will be achieved by directing water from the clarification pond to the ore preparation plant.

- All runoff from the blending stock pile (which may contain up to 100% low magnesium saprolite) will be diverted to the ore preparation plant.

Water quality information for runoff from different land areas and the sources of this information used for modelling are summarized in Table 3.9-2. Water quality in receiving watercourses was based on average baseline concentrations of substances in watercourses within the mine area for the wet or dry seasons. The wet and dry seasons corresponded to the months of December to March and April to November, respectively, which is consistent with the seasons used in the hydrology assessment.

Table 3.9-2 Summary of Water Quality Information Used for Assessment

| Area | Description | Source |
|---|---|---|
| mine areas | predicted runoff water quality from mined areas | geochemistry assessment (Volume B, Section 3.2) |
| waste areas | predicted runoff water quality from waste areas | geochemistry assessment (Volume B, Section 3.2) |
| undisturbed areas | average baseline concentration of watercourses within the mine area | baseline water quality (Volume I, Appendix 9.1) |
| disturbed areas (other than mined or waste areas) | baseline concentrations for the samples with maximum total suspended solids results | baseline water quality (Volume I, Appendix 9.1) |
| reclaimed areas | average baseline concentration of watercourses within the mine area | baseline water quality (Volume I, Appendix 9.1) |
| pond area | concentration of zero was used to represent substance concentrations in precipitation | not applicable. |

All water quality variables, for which sufficient data were available, were modelled at the mine area (Table 3.9-3). Values for pH were not predicted with the mass balance model. However, the potential range of pH values at the outlets of the six basins was characterized for baseline, operations and post-closure scenarios using data from sources summarized in Table 3.9-2.

Table 3.9-3 Water Quality Variables Assessed

| Group | Water Quality Variables |
|--------------|---|
| conventional | total alkalinity |
| major ions | calcium, chloride, fluoride, magnesium, potassium, sodium, sulphate |
| nutrients | ammonia, nitrate and nitrite |
| total metals | aluminum, antimony, arsenic, barium, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silicon, thallium, tin, uranium, vanadium and zinc |

Sediment Quality

Changes in sediment quality were predicted based on US EPA (1999) guidelines for calculating benthic sediment concentrations. The equations provided by USEPA (1999) estimate the proportion of a substance within a water body that exists in the 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.

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 and inputs to the model are provided in Volume I, Appendix 9.2.

Changes in sediment concentrations were assessed for aluminum, antimony, arsenic, cadmium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, thallium, vanadium and zinc. These metals were assessed in the water quality model and had baseline sediment quality data for calibrating the sediment quality equations. Baseline sediment quality data was not available for chromium; however, changes in chromium concentration in benthic sediments due to the project were assessed because of appreciable increase in water column concentration of this metal above background levels.

3.9.5.2 Assessment Criteria

Comparison to Baseline Values and Guidelines

Maximum concentrations predicted for the wet and dry seasons during operations and at post-closure were compared to corresponding baseline values. During operations or post-closure, maximum predicted concentrations exceeding the corresponding baseline concentrations by 10% or greater were considered an

appreciable change. Because detection limits between baseline wet and dry season data are substantially different, wet season results were only compared to wet season baseline data and dry season results were only compared to dry season baseline data. Predicted concentrations that are appreciably higher than baseline concentrations were compared to drinking water and aquatic life guidelines. The World Health Organization (WHO) drinking water quality guidelines (WHO 2004) and the South African Aquatic Ecosystems guidelines (Department of Water Affairs and Forestry 1996) were used for comparison.

All predicted concentrations of chromium are representative of total chromium concentrations. However, the South African Ecosystems guidelines for chromium are based on hexavalent and trivalent chromium. Although the most conservative approach is to assume that all chromium is in the hexavalent form, chromium is expected to be a combination of both trivalent and hexavalent chromium. Therefore, total chromium results were compared to both trivalent and hexavalent South African Ecosystems guidelines.

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

Results of the comparison to baseline and guideline values are summarized in Volume I, Appendix 9.1.

Characterization of Changes in Water Quality

Six representative key substances were selected to characterize potential changes in water quality from the mine area, including cadmium, chromium, cobalt, lead, nickel and zinc. Cadmium, chromium, lead and zinc were chosen because predicted results from the operations scenarios of these four substances 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 at the clarification pond outlets and downstream assessment nodes for the six key substances were summarized for each basin. The effects of the predicted changes on biological receptors are assessed separately in Volume B for flora (Section 4.1), fauna (Section 4.2), fish and aquatic resources (Section 4.3) and human and ecological health (Section 5.4).

3.9.5.3 Mitigation

The following mitigations, which were based on the current mine design, were incorporated into the water quality model:

- application of erosion and sediment control systems;
- utilization of designed settling and clarification ponds (with flocculant treatment capability) prior to downstream release;
- assumption of 25% of the pit area is exposed at each of the pits at any given time during operation, which means the remaining 75% of the area is either undisturbed or reclaimed ;
- if necessary, diverting runoff from active mine, waste and ore storage areas to the ore preparation plant;
- progressively reclaiming mine and waste areas through revegetation; and
- establishing a sustainable reclamation drainage plan at closure.

Designed erosion and sediment control systems, will minimize sediments and adsorbed substances into downstream systems. The use of flocculants in the collection and clarification ponds will also reduce total suspended solids (TSS) and adsorbed substances in the ponds, prior to downstream discharges.

Runoff that has been in contact with low magnesium saprolite (LMS) is expected to have elevated chromium levels compared to baseline runoff from undisturbed areas. The operations strategy of the mine is intended to reduce the amount of runoff that comes into contact with LMS through minimizing the amount of exposed LMS in an operating area. It is assumed that a maximum of 25% of an operating pit area will be mined at any given time. The remaining 75% of the total pit area will be covered, reclaimed or undisturbed.

Runoff with high substance concentrations will be diverted from active mine, waste and ore storage areas to the ore preparation plant, which will minimize substance loading into the receiving waters downstream of the mine area.

Progressive reclamation of mined and storage areas will minimize disturbed areas that can potentially contribute substance loading to runoff water. Mulch and non-tailings native material will be used to form a base for vegetation to grow. Revegetation will be accomplished with multiple plant species that grow quickly under a wide range of conditions. As the vegetation becomes denser, this layer of soil and vegetation will create a barrier between runoff and mine or waste material.

A reclamation landscape with sustainable drainage and vegetation cover will be established at closure. The closure landscape will have slopes and drainage channels that will minimize erosion and transport of soil material into downstream receiving waters.

In addition to the above mitigation measures water quality will be protected through the use of designed storage and handling areas for waste materials, the application of a waste management plan and an emergency response plan all of which will be part of an operations environmental management system (Volume H, Appendix 6).

3.9.5.4 Results

Water Quality

Model results for all scenarios, basins, assessment nodes and months are presented in Tables 9.2-3 to 9.2-12 in Volume I, Appendix 9.2. These results were provided to disciplines that assessed human, flora, fauna and aquatic life health effects.

During post-closure, predicted maximum concentrations for all substances are at or below baseline levels. Therefore, post-closure water quality is not discussed further in this section. Predicted maximum concentrations in each of the six water basins for the operation scenarios were compared to baseline concentrations, and drinking water and aquatic life guideline values (Tables 9.2-3 to 9.2-12 in Volume I, Appendix 9.2). For the operation scenarios, concentrations of six substances (nitrate, fluoride, sodium, sulphate, barium and chromium) at the outlet of the clarification ponds are predicted to be higher than baseline concentrations during the wet season (Table 3.9-4). However, the predicted concentrations for these six substances are below the corresponding drinking water guideline values. Chromium concentrations are predicted to exceed the South African Aquatic Ecosystem guideline value, but the effects of the exceedance on biological receptors are further assessed as described above in Section 3.9.5.2 (Assessment Criteria).

Under dry season conditions of the operations phase, concentrations of fifteen substances at the outlet of the clarification ponds are predicted to increase above baseline values (Table 3.9-4). Predicted concentrations of each of these fifteen substances are below drinking water guideline values, but predicted concentrations for four substances (cadmium, chromium, lead and zinc) are above corresponding Aquatic Ecosystem guideline values for South Africa. However, predicted increases in zinc, cadmium and lead are marginal. Furthermore, background conditions contribute appreciably to the concentrations

of cadmium and lead that are above the South African guideline values. The biological receptor effects of the predicted increase in substance concentrations are further assessed as described in Section 3.9.5.2 (Assessment Criteria).

Table 3.9-4 Comparison of Maximum Predicted Concentrations with Baseline Levels and South African Guideline Values

| Basin | Antsahalava | | Sahaviara | | Sahamarirana | | Torotorofotsy | | Sakalava | | Ankaja | |
|-----------------------------|-------------|-----|-----------|-----|--------------|-----|---------------|-----|----------|-----|--------|-----|
| Season | Wet | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet | Dry |
| nitrate (NO ₃) | ✓ | - | - | - | - | - | - | - | - | - | - | - |
| nitrite (NO ₂) | - | ✓ | - | ✓ | - | - | - | ✓ | - | - | - | - |
| fluoride (F) | ✓ | ✓ | - | - | - | - | - | - | - | - | - | - |
| sodium (Na) | ✓ | ✓ | ✓ | - | - | - | - | - | - | - | - | - |
| sulphate (SO ₄) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| antimony (Sb) | - | ✓ | - | ✓ | - | ✓ | - | ✓ | - | ✓ | - | ✓ |
| arsenic (As) | - | ✓ | - | ✓ | - | ✓ | - | ✓ | - | ✓ | - | ✓ |
| barium (Ba) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| cadmium (Cd) | - | • | - | - | - | - | - | • | - | • | - | • |
| chromium (Cr) ¹ | • | • | • | • | • | • | • | • | • | • | • | • |
| chromium (Cr) ² | ✓ | • | ✓ | ✓ | • | • | • | • | • | • | • | • |
| lead (Pb) | - | - | - | - | - | - | - | • | - | • | - | • |
| molybdenum (Mo) | n/a | ✓ | n/a | ✓ | n/a | ✓ | n/a | ✓ | n/a | ✓ | n/a | ✓ |
| selenium (Se) | - | ✓ | - | ✓ | - | ✓ | - | ✓ | - | ✓ | - | ✓ |
| thallium (Tl) | n/a | ✓ | n/a | ✓ | n/a | ✓ | n/a | ✓ | n/a | ✓ | n/a | ✓ |
| uranium (U) | - | ✓ | - | ✓ | - | ✓ | - | ✓ | - | ✓ | - | ✓ |
| zinc (Zn) | - | • | - | • | - | • | - | ✓ | - | ✓ | - | ✓ |

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

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

• Above baseline and South Africa Ecosystems Guidelines (Department of Water Affairs and Forestry 1996).

n/a Baseline data for this substance was not available for the wet season.

Notes: ¹ Compared to hexavalent South African Ecosystems Guidelines for chromium.

² Compared to trivalent South African Ecosystems Guidelines for chromium.

Chromium had the greatest increase in predicted concentrations due to project-related activities. The source of the higher chromium is the runoff from the mine and waste areas. Predicted concentrations of chromium in the receiving waters were greater for basins in the Analamay area than for the Ambatovy basins. Predicted chromium concentrations in the runoff from the Analamay area range between 0.36 and 0.41 mg/L compared to concentrations from the Ambatovy area, which are between 0.02 and 0.11 mg/L (Volume B, Section 3.2).

The downstream extent of predicted concentrations that were above South African guideline values was reviewed in Tables 9.2-3 to 9.2-12 in Volume I, Appendix 9.2. During operations, concentrations of chromium are predicted to be below WHO Guideline values, but above South African Ecosystems Guideline values at the clarification pond outlet in all six basins based on the conservative assumption that all chromium is in the hexavalent form. However, in the Ambatovy basins, predicted chromium concentrations are below the South African Ecosystems Guideline value for hexavalent chromium at distances of 1.5 to 6.5 km downstream of the clarification ponds due to dilution from undisturbed watershed areas. In the Analamay basins, predicted chromium concentrations were higher than the South African guideline values for hexavalent chromium at the most downstream assessment nodes, which ranged from 5 to 10 km downstream of the clarification ponds. The downstream extent of predicted exceedances of the trivalent guideline for chromium is less than the extent of exceedances based on the hexavalent form. The biological receptor effects of the predicted increase in chromium concentrations are assessed further as described in Section 3.9.5.2 (Assessment Criteria).

Baseline concentrations of cadmium and lead are above South African Ecosystems Guidelines and were predicted to increase marginally during operations in four and three basins, respectively, due to runoff from disturbed areas. Concentrations of cadmium and lead in runoff from the mine and waste areas are predicted to be less than baseline values and therefore, are not contributing to the predicted increase. The biological receptor effects of these predicted increases in cadmium and lead concentrations are assessed further as described in Section 3.9.5.2 (Assessment Criteria). Concentrations of cadmium and lead return to baseline levels in the post-closure scenario.

In the Ambatovy basins, predicted zinc concentrations increased marginally and were above South African Ecosystems Guidelines at the pond outlet. The concentrations decreased to below guidelines at 7.5 km, 3 km and 2 km downstream of the outlet of the Antsahalava, Sahaviara, and Sahamarirana basins, respectively, in the operations scenarios. The biological receptor effects of the predicted increase in zinc concentrations are assessed further as described in Section 3.9.5.2 (Assessment Criteria). Post-closure concentrations of zinc are predicted to return to baseline levels.

Predicted concentrations of nickel and cobalt were low for all scenarios in all basins. Predicted concentrations for these two metals decreased during operations compared to baseline levels. Post-closure concentrations of nickel and cobalt are predicted to return to baseline concentration levels.

Predicted changes in substance concentrations in the Torotorofotsy River were used as a guide for determining project-related effects on the Torotorofotsy Wetlands. The Torotorofotsy River is the main upstream tributary of the wetlands that would potentially be affected by the project. Water quality changes in the Torotorofotsy River for the six key representative substances are summarized in Table 3.9-5.

Table 3.9-5 Concentrations of Key Water Quality Variables in the Torotorofotsy River and Torotorofotsy Wetlands (Observed and Predicted)

| Parameters | Units | WHO Drinking Water Guidelines ¹ | South African Ecosystems Guidelines ² | Model Baseline (Torotorofotsy River) | | Predicted Operations (Torotorofotsy River) | | Predicted Post-closure (Torotorofotsy River) | | Baseline Torotorofotsy Wetlands | |
|---------------|-------|--|--|--------------------------------------|---------------|--|---------------|--|---------------|---------------------------------|-------|
| | | | | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. |
| cadmium (Cd) | mg/L | 0.003 | 0.00015 ^{3,4} | 0.0005 | 0.0050 | 0.0005 | 0.0050 | 0.0005 | 0.0050 | <0.001 | <0.01 |
| chromium (Cr) | mg/L | 0.05 ⁵ | 0.014/0.024 ^{6,7} | 0.006 | 0.008 | 0.018 | 0.019 | 0.006 | 0.008 | <0.003 | 0.010 |
| cobalt (Co) | mg/L | - | - | 0.002 | 0.005 | 0.002 | 0.005 | 0.002 | 0.005 | 0.002 | 0.010 |
| lead (Pb) | mg/L | 0.01 | 0.000475 ^{3,7,8} | 0.005 | 0.050 | 0.005 | 0.050 | 0.005 | 0.050 | <0.01 | <0.1 |
| nickel (Ni) | mg/L | 0.4 ⁵ | - | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | <0.003 | 0.010 |
| zinc (Zn) | mg/L | 0.02 ⁴ | 0.0036 ⁷ | 0.003 | 0.014 | 0.003 | 0.014 | 0.002 | 0.014 | <0.001 | <0.01 |

- Notes: 1 World Health Organization (WHO) 2004 Guidelines for drinking water quality, 2nd edition. Geneva, World Health Organization. Results in **bold** are above baseline concentrations by 10% and above South African guidelines.
- 2 South African Water Quality Guidelines Volume 7 Aquatic Ecosystems (1996) Second Edition. Department of Water Affairs and Forestry.
- 3 Based on an alkalinity value of less than 60 mg/L.
- 4 Based on the lower of two guideline values: 0.0003 mg/L (general) and 0.00015 mg/L (cold-water adapted fish species).
- 5 Provisional guideline value, as there is evidence of a hazard, but the available information on health effects is limited.
- 6 South African guidelines presented for chromium are based on hexavalent chromium (0.014mg/L) and trivalent chromium (0.024 mg/L); see text.
- 7 South African guidelines are based on the dissolved portion of this metal.
- 8 Based on a dissolved saturation of at least 80%.
- no guideline.

During operations, the predicted maximum concentration of chromium is higher than baseline concentrations for the Torotorofotsy River and Torotorofotsy Wetlands. Therefore, mine-related activities may contribute chromium to the wetlands. However, the resulting concentrations in the wetlands would be lower than the WHO drinking water guideline value since predicted maximum concentrations of chromium in the Torotorofotsy River are lower than the guideline value. The South African Ecosystems Guideline value for hexavalent chromium, but not trivalent chromium, is predicted to be exceeded in the Torotorofotsy River. Potential exceedances in the Torotorofotsy Wetlands would be lower in magnitude due to dilution from other source waters into the wetlands. The biological receptor effects of a potential increase in chromium concentration

in the wetlands are assessed further as described in Section 3.9.5.2 (Assessment Criteria).

Two additional water quality substances, cadmium and lead, are predicted to be marginally above baseline and above South African Ecosystems Guideline values at the outlet of the clarification pond discharging to the Torotorofotsy River. However, the concentrations of these two metals return to baseline levels within 5,000 m downstream of the pond outlet, which is upstream of the Torotorofotsy Wetlands. Therefore, no changes in the concentrations of cadmium and lead are predicted in the Torotorofotsy Wetlands. During post-closure, predicted concentrations of cadmium and lead were at or below baseline levels at the clarification pond outlet to the Torotorofotsy River. Predicted concentrations of other key representative water quality substances during operations and post-closure are similar to the corresponding baseline values in the Torotorofotsy River and Torotorofotsy Wetlands. Therefore, the project is predicted to result in negligible changes in these water quality constituents within the Torotorofotsy Wetlands during post-closure.

As described in Section 3.9.5.1, the combined effect of sediment control measures and the relative volume to be pumped from the Mangoro River to the ore preparation plant will result in negligible substance loading to the river during construction and operation of the water intake pipe. Furthermore, flows from the mine areas will not reach the river. Therefore, no changes in water quality are predicted for the Mangoro River due to the project.

Sediment Quality

Sediment quality predictions corresponding to the maximum change in water column concentrations are presented in Table 9.2-13 in Attachment 1, Appendix 9.2 of Volume I. These results were provided to disciplines assessing aquatic, human and wildlife health.

Predicted maximum substance concentrations in benthic sediment do not increase above baseline levels during post-closure in all river basins. The sediment quality predictions indicate that changes in sediment concentrations of arsenic, selenium and thallium due to the project during operations are marginally greater than baseline values. The maximum predicted arsenic concentration in benthic sediment is well below the Interim Sediment Quality Guideline (ISQG) (CCME 2002). Selenium and thallium do not have Canadian sediment quality guidelines (Table 3.9-6), therefore no comparisons of the predicted concentrations to guideline values are presented. Chromium concentrations were also predicted to increase by about 1 mg/kg. Absolute values for chromium sediment concentration could not be compared to CCME guideline values

because no baseline data was available. However, a predicted increase in concentration of 1 mg/kg is considered to be small relative to the CCME ISQG of 37.3 mg/kg.

Table 3.9-6 Comparison of Predicted Maximum Sediment Quality Concentrations During Operations With Guideline Values

| Substance | Results Above Baseline Sediment Concentration | Results Above Canadian Sediment Guidelines | |
|-----------|---|--|------------------|
| | | ISQG ¹ | PEL ² |
| aluminum | - | | |
| antimony | - | | |
| arsenic | ✓ | x | x |
| barium | - | | |
| boron | - | | |
| cadmium | - | | |
| chromium | ✓* | x* | x* |
| cobalt | - | | |
| copper | - | | |
| lead | - | | |
| manganese | - | | |
| mercury | - | | |
| nickel | - | | |
| selenium | ✓ | NG | NG |
| thallium | ✓ | NG | NG |
| vanadium | - | | |
| zinc | - | | |
| iron | - | | |

Notes: ¹ Probable Effect Level (CCME 2003);

² Interim Sediment Quality Guideline (CCME 2003);

- = not above baseline (less 10% difference between baseline and maximum predicted concentration) or guideline;

✓ = project-related changes in water quality concentrations are above baseline by 10% or greater;

* = because baseline concentrations were not available for chromium, it was assumed that predicted maximum concentrations were above baseline concentrations. If a 1 mg/kg increase would have caused concentrations to increase above the ISQG, then this would have resulted in an increase of less than 10% from baseline;

blank cell = not compared to guidelines when project-related activities results in less than 10% difference in maximum predicted concentration compared to baseline; and

NG = no applicable guideline.

Changes in sediment concentrations in the Torotorofotsy Wetlands are expected to be less than the maximum predicted changes described above. The predicted increase in sediment concentrations decreases downstream of the clarification

pond in the Torotorofotsy basin. Therefore, changes in sediment quality in the Torotorofotsy Wetlands are expected to be less than the maximum predicted sediment quality changes in the Torotorofotsy River. Similar to the other river basins, negligible changes in sediment quality in the Torotorofotsy Wetlands would occur during post-closure conditions due to negligible changes predicted for the Torotorofotsy River.

3.9.6 Impact Analysis

3.9.6.1 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 and groundwater flows are medium and low, respectively, as discussed in Volume B, Sections 3.8 and 3.7. Baseline groundwater quality is not well understood in the mine area; however, the effect of this limited information on predicted changes in water and sediment quality is estimated to be medium to low. The prediction confidence of the runoff quality from the mine and waste areas are low to medium as discussed in Volume B, Section 3.2.

The number of pooled data sets for one year of sampling from the watercourses ranged between eight and ten for each of the two (wet and dry) seasons. During the dry season, the baseline condition of general surface water quality in the LSA is adequately understood, resulting in moderate certainty in the data. 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.

Conservative assumptions were used in the water quality assessment, including:

- no attenuation of water quality substances, except suspended solids, in the collection or clarification ponds; and
- no geochemical transformations and settling in the receiving waters; and
- total chromium occurring in the hexavalent form.

The prediction confidence is also dependent on the success of the effective mitigations proposed, including erosion control, water management and sustainable reclamation. The proposed mitigation methods, such as sediment

ponds and flocculation to remove suspended solids, are commonly used and are known to be effective. The proposed reclamation methods are also based on standard practices and known to be effective in reducing the effects of mining on water and sediment quality during post-closure. Furthermore, implementation of these measures is relatively simple. Therefore, there is high to medium confidence in the success of these mitigations.

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

3.9.6.2 Monitoring

Routine water and sediment quality monitoring program will be established to ensure operational controls are functioning properly and downstream systems are being protected and to identify any unanticipated effects. The purpose of identifying unanticipated effects and their cause is to adaptively manage or mitigate these impacts quickly and effectively.

In addition, before construction, natural ponds and pools in the undisturbed area of the mine area will be further monitored to determine sensitivity to any potential acidification due to air emissions.

During operations and post-closure conditions, on a routine basis, water and sediment samples will be collected from each of the six clarification pond outlets, downstream locations along the receiving watercourses, and within the Torotorofotsy Wetlands. During construction of water intake in the Mangoro River, suspended solids will also be monitored in the river.

3.9.6.3 Conclusions

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

- Runoff from the mine and waste areas to the clarification ponds is a source of chromium and, to a small degree, zinc loading to receiving watercourses during project operations.
- Through various design and operational mitigations, the project will not cause chromium concentrations to increase above WHO drinking water guideline values in receiving waters downstream of the mine areas.

- Chromium is the key substance of concern with project-related loadings during operations potentially increasing concentration of this substance in all basins above both baseline concentrations and the most conservative (i.e., based on the hexavalent form) South African guideline value for aquatic life.
- The highest concentrations of chromium will occur in the basins draining the Analamay area.
- During the project operations phase, concentrations of zinc in the Ambatovy basins (Antsahalava, Sahaviara and Sahamarirana) will potentially increase marginally above background concentrations and the South African guideline value for aquatic life.
- Water quality in the Torotorofotsy Wetlands during the project operations phase will be similar to baseline substance concentrations, due to appreciable dilution of water released from the clarification pond in the Torotorofotsy basin.
- Post-closure water quality concentrations in receiving waters for all basins within the mine area will return to baseline levels after constructing sustainable reclamation and implementing effective mitigations.
- Negligible changes in water and sediment quality will occur in the Mangoro River due to the relative volume to be pumped from the Mangoro River to the ore preparation plant and erosion control measures implemented at the water intake site.
- Sediment quality in receiving watercourses and water bodies during mine 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.

3.10 VISUAL AESTHETICS

3.10.1 Introduction

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

3.10.2 Study Area

The mine Local Study Area (LSA) for visual aesthetics is an area within 5 km of the major mine disturbances, as shown in Volume A, Figure 7.2-1. This study area is designed to include the limits of the area in which the mine is close enough to be a prominent visible feature within the local terrain.

3.10.3 Baseline summary

The ore bodies are located in a densely forested area. The remnants of an eroded plateau make up the two ore bodies. To the west, the plateau is flanked by a broad alluvial plain of the Mangoro River. To the east is the Torotorofotsy – Mokaranana wetlands system and forested hills. Presently, views of the mine area from all directions are dominated by lush vegetation, although when viewing the surface of the Ambatovy and Analamay ore bodies from close range, it is clear that the vegetation in these areas is stunted and has a different composition, and that the Analamay ore body has especially sparse vegetation due to recent fires. Views of the mine area are possible from several areas in the surrounding landscape, including high areas on hilltops (including in Mantadia National Park), roadways such as Route National (RN) 44, and various small towns and agricultural areas.

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 3.10-1. Baseline views from key viewpoints M1 to M5 are presented in Volume I, Appendix 11.1, Attachment 1, Photographs 4 through 8.

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

Table 3.10-1 Key Viewpoints: Mine Site

| Viewpoint Number | Viewpoint Name | GPS location (UTM Zone 39S) | Possible Viewers | Baseline View Characteristics |
|------------------|--|-----------------------------|---|---|
| M1 | Torotorofotsy Wetlands | E 222731 N 7910838 | local residents ecotourists | relatively natural and undisturbed; heavy vegetation cover |
| M2 | RN44 | E 208407 N 7913684 | local residents travellers and tourists | human-influenced corridor with extensive land use; views of primary forest in distance |
| M3 | mine access road | E 210854 N 7912564 | local residents | partially disturbed and cleared by human use; patches of primary forest visible |
| M4 | northwest view at mine near access corridor and agricultural area | E 213954 N 913870 | local residents | foreground area is cleared for human use; background consists of primary or secondary zonal and azonal forests |
| M5 | southeast view at mine near access corridor and agricultural area | E 214088 N 913007 | local residents | foreground area is cleared for human use; background consists of primary or secondary zonal and azonal forests |

Note: GPS = global positioning system; UTM = universal transverse mecatator.

3.10.4 Issue Scoping

In public consultations, the main question regarding aesthetics has been: how will changes in visual aesthetics affect tourism? This question has been raised both by local residents, in meetings with the commune of Ambohibary, and by the National Association for the Management of Protected Areas (ANGAP). 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 stock piles, ponds, dikes and pits;
- generation of visible clouds of dust in dry periods, as well as some locally visible fossil fuel emissions;
- operating lights during the night; and
- the presence of buildings, facilities and infrastructure, some of which will be visible from outside of the mine area.

The key question for visual aesthetics is:

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

Most visual effects will occur during the construction and operation phases of the project, as shown in the linkage diagram for visual aesthetics (Volume H, Appendix 9).

3.10.5 Impact Assessment

During construction and operation phases, vegetation will be cleared, landscape features will be altered, industrial buildings will be constructed and dust and visible plumes will be released from the mine site. Following closure, most sources of visual impacts will be removed, but landforms will be altered.

3.10.5.1 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 mine were selected and ground-level views were generated using topographic models. The future views were compared with baseline views in these cases.

An overall overhead view of the mine site 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, and was not used to evaluate visual impacts.

3.10.5.2 Assessment Criteria

The assessment criteria used for visual aesthetics are presented in Table 3.10-2.

Table 3.10-2 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 |

3.10.5.3 Mitigation

Project design will allow direct impacts of the mine development to avoid the Torotorofotsy Wetlands, minimizing visual effects on tourists in this area.

During construction and operations, fully shielded lights will be used at project facilities, and the lights will be directed away from nearby houses, villages and conservation areas to minimize effects on both people and wildlife.

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

During the operations and closure phases, reclamation will occur. Slope design and erosion control will minimize both short and long-term erosion. Closure landforms will be designed such that there will be continuity of landforms and watershed systems between undisturbed land and previously reclaimed areas. Revegetation with native species will allow the affected landscape to blend with the existing unaffected forest.

3.10.5.4 Results

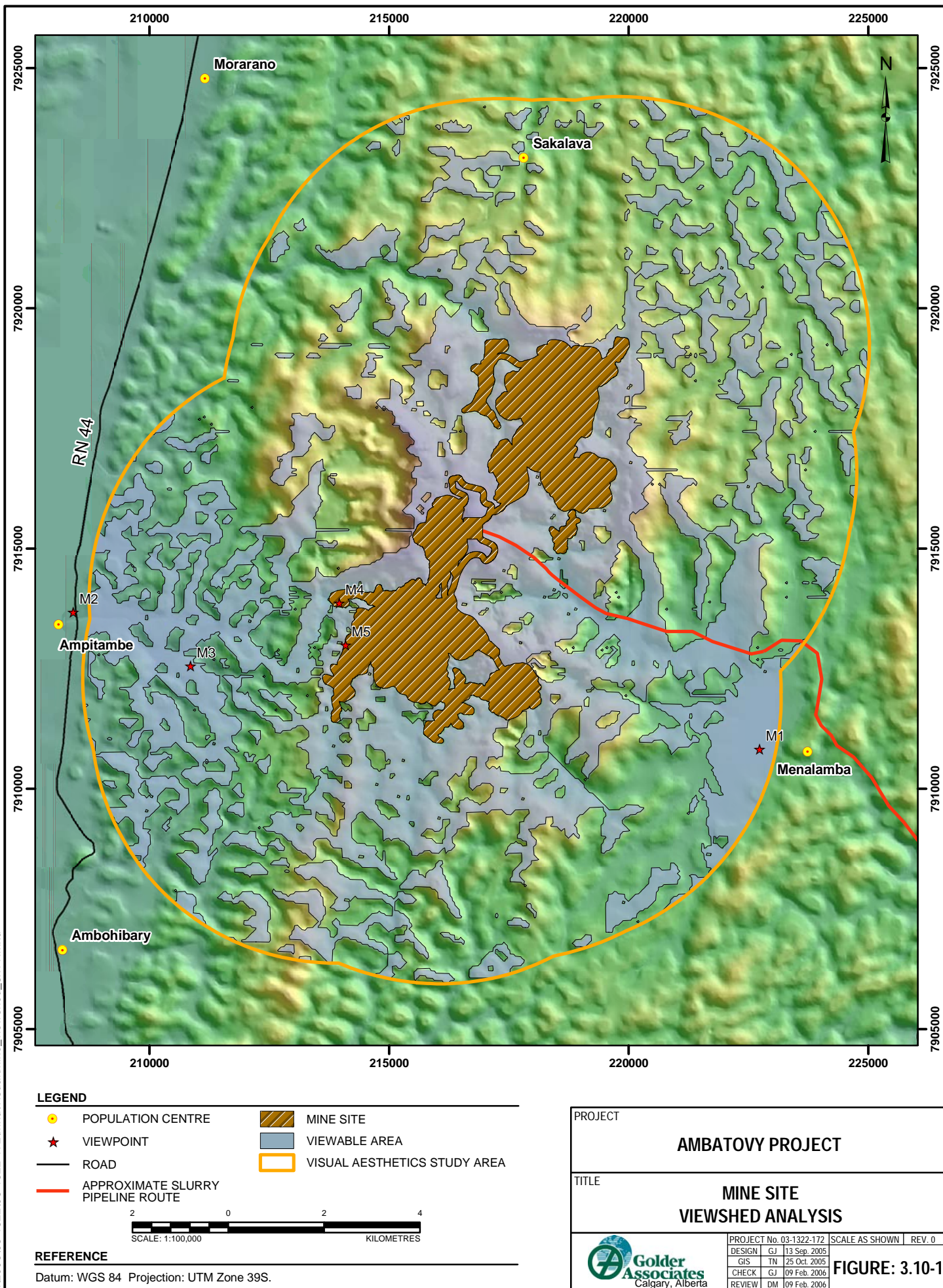
A viewshed evaluation for the mine topography at its maximum extent (20 year snapshot) is presented in Figure 3.10-1. The viewshed evaluation shows that within the study area (all areas 5 km from the mine or closer), about one-third of the area offers possible views of mine development. However, this is a conservative estimate of the viewshed because it does not include the effects of vegetation, which is relatively dense in most of the LSA and will obscure views from many areas.

The viewshed analysis demonstrates that views will be possible from the areas of the Torotorofotsy Wetlands Ramsar site and from parts of the mine access road, although with vegetation cover considered these views may not represent large visual impacts. Although the viewshed also extends beyond the LSA, effects more than 5 km from the project (such as those from RN44) are expected to be negligible, as the project will be a small feature on the horizon.

Groups of people likely to be viewing the mine area include local residents, passers-by along RN44, and tourists, particularly those visiting the Torotorofotsy Wetlands. The visual effect of the mine on people will vary widely based on personal perception, and may affect the enjoyment of the natural aesthetic qualities of the area. For viewers within the viewshed, perceptions of the aesthetic effects of the mine may be affected by:

- the surrounding landscape, including landforms, vegetation and general level of modification;
- the type of mine disturbance being viewed, including form, texture, colour, size and level of contrast with the surrounding landscape;
- the distance between the observer and the impact;
- 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.

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Excavation of ore will remove an average of 40 m and a maximum of about 90 m from the upper portion of several hilltops that comprise the ore bodies. Stock pile areas and engineered embankments will be developed. Some of these changes in topography could be visible in areas outside of the mine, such as RN44, the Torotorofotsy Ramsar Site and high-elevation points of Mantadia National Park. However, the hilltops associated with the ore body are not of particular scenic importance, and the viewing distances from RN44 and Mantadia National Park will be long, decreasing the magnitude of impacts in these locations.

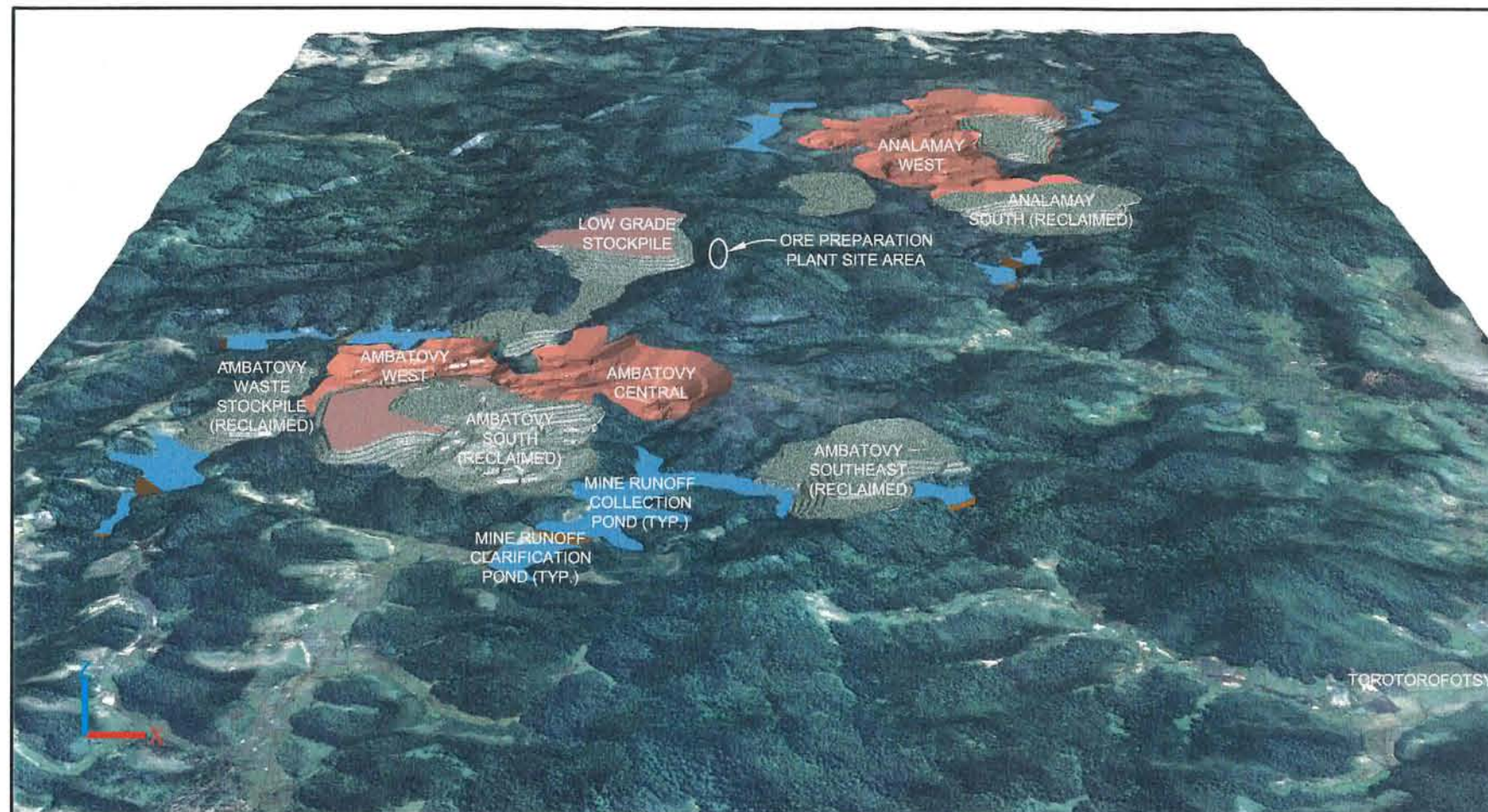
A schematic overhead view of future mine site topography at year 20 (maximum development) is presented in Figure 3.10-2.

An impacted view from Viewpoint M1 (Table 3.10-1) is presented in Figure 3.10-3. This viewpoint is in an area accessible to tourists in the Torotorofotsy Wetlands. The view is directed toward the mine, and shows that very small parts of the mine topography will be visible from the wetlands, including an embankment of the Analamay West mining area and the ore preparation plant site area. Because of topography and distance, these impacts present a very small impact.

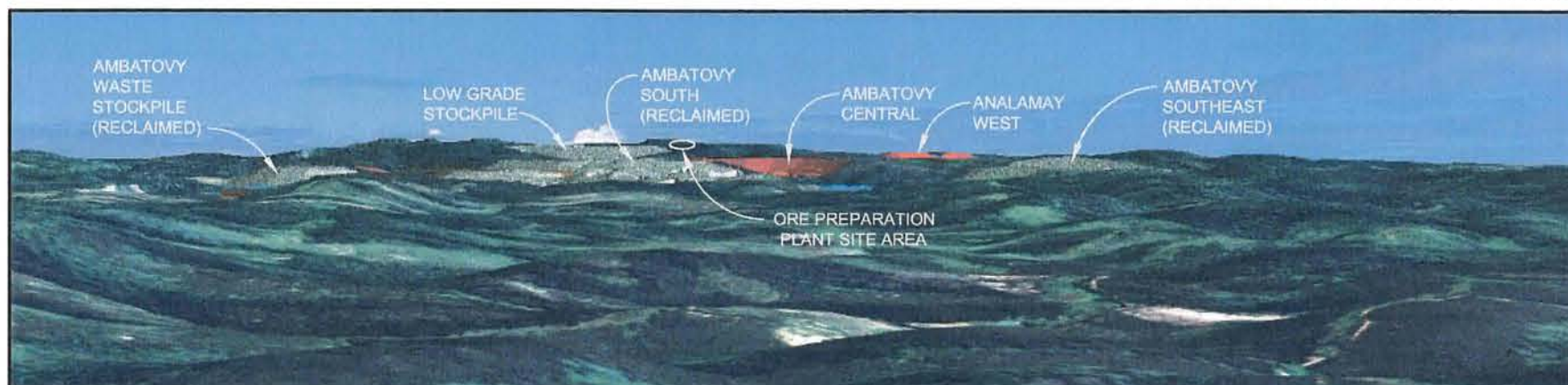
An impacted view from Viewpoint M3 (Table 3.10-1) is presented in Figure 3.10-4. This viewpoint is along the mine access road, in proximity to areas frequented by local land users. There are several possible views of the mine along the access road, but this view is typical and shows part of the reclaimed Ambatovy South mine (center), active Ambatovy Central and Analamay West mining areas (center-right), and reclaimed southwest Ambatovy Mining area (right). The views are relatively distant, however, presenting a small impact.

Plume visibility depends on the water vapour content of the plume, temperature of the plume, exhaust rate, and the ambient temperature and relative humidity. Plume visibility will vary seasonally. However, during at least some of the year, plumes will be visible in the surrounding area, including the Torotorofotsy Wetlands.

3REF FILE(S): IMAGE FILE(S): DYNOLITE Mining Area - Aerial View Looking North Mining Area - Perspective View Looking From Torotorofotsy Mining Area - Perspective View Looking North Tollings Area - Aerial View Looking West Tollings Area - Perspective View from Spine Road



AERIAL VIEW LOOKING NORTH



PERSPECTIVE VIEW LOOKING NORTH



PERSPECTIVE VIEW LOOKING FROM TOROTOROFOTSY

LEGEND:

- RECLAIMED AREA
- EMBANKMENT
- WATER
- ACTIVE MINING AREA
- ACTIVE STOCKPILE

| AMBATOVY PROJECT | | | |
|-------------------------------------|--------------------------|-----------|-----------|
| VISUAL PRESENTATION FOR MINING AREA | | | |
| YEAR 27 - END OF OPERATIONS | | | |
| Knight Piésold CONSULTING | P/A NO. NB301-00116/4 | REF. - | REV. - |
| | FIGURE 3.10-2 | | |

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| | | | |
|--|-------------------------|----|--------------|
| PROJECT | | | |
| AMBATOVY PROJECT | | | |
| TITLE | | | |
| VIEW NORTHWEST FROM VIEWPOINT M1 (TOROTOROFOTSY) AFTER DEVELOPMENT (YEAR 27 OF OPERATIONS) | | | |
|  | PROJECT No. 03-1322-172 | | NOT TO SCALE |
| | DESIGN | GJ | 13 Sep. 2005 |
| | GIS | TN | 25 Oct. 2005 |
| | CHECK | GJ | 09 Feb. 2006 |
| | REVIEW | DM | 09 Feb. 2006 |
| | | | REV. 0 |

FIGURE: 3.10-3



| | | | | | |
|---|--|-------------------------|----|--------------|----------------|
| PROJECT | | | | | |
| AMBATOVY PROJECT | | | | | |
| TITLE | | | | | |
| VIEW NORTHEAST FROM VIEWPOINT M3 (MINE ACCESS ROAD) AFTER DEVELOPMENT (YEAR 27 OF OPERATIONS) | | | | | |
|  | | PROJECT No. 03-1322-172 | | NOT TO SCALE | REV. 0 |
| | | DESIGN | GJ | 13 Sep. 2005 | FIGURE: 3.10-4 |
| | | GIS | TN | 25 Oct. 2005 | |
| | | CHECK | GJ | 09 Feb. 2006 | |
| | | REVIEW | DM | 09 Feb. 2006 | |

3.10.5.5 Impact Analysis

Residual Impacts

Following mitigation, the residual effects during each project period are summarized in Table 3.10-3.

Table 3.10-3 Potential Effects and Residual Impacts for Visual Aesthetics

| Project Period | Potential Effects | Mitigation | Residual Impacts |
|-----------------------------|--|--|---|
| construction and operations | clearing of land and changes in mine landforms | progressive reclamation | low-magnitude modification of visible landscape from key viewpoints |
| | changes in visible facilities and machinery | location of activity is almost entirely out of public view | negligible impact on key viewpoints |
| | changes in light pollution | fully shielded lights directed away from viewers | negligible impact on key viewpoints |
| | changes in visible emissions and dust | dust control measures | low-magnitude effects which may be visible from longer distances |
| closure | clearing of land and changes in mine landforms | contouring and revegetation of landforms to a natural appearance | low magnitude / long-term modification visible landscape |
| | changes in visible facilities and machinery | decommissioning and removal of facilities and machinery | none |

Clearing of land and mine landform changes will occur throughout construction and operations phases; progressive reclamation will be initiated during the operations phase and will be complete following closure. Among the mine landforms that may be visible are open pits with steep pit walls, waste areas and pond systems. The magnitude of landform visual impacts is considered moderate during operations and low following closure.

The geographic extent of impacts is local, as rough topography obscures the views of most areas outside the LSA. The most prominent impacts (during operations) are medium-term, while the lower-magnitude impacts of the reclaimed mine landforms are long-term. Landform impacts are not reversible, as the landscape will not be returned to its initial state. Viewing frequency is medium, as viewers will intermittently be at specific viewpoints from which the project will be visible. Overall, the environmental consequence for visual effects is low for the construction, operation and closure phases.

The construction of mine facilities will have an impact negligible in magnitude, since such facilities will be very difficult to see from outside the mine area itself. 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 mine facilities for visual aesthetics will be negligible.

Night time lighting 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 medium. The overall environmental consequence of light pollution for visual aesthetics will be negligible.

Release of dust and visible emissions will have an impact low in magnitude. Mitigation such as dust control measures will be implemented. Effects are regional in extent because visible emission plumes may be visible from outside the LSA. Effects are medium-term in duration (during construction and operations only) and are reversible. Viewing frequency is expected to be medium. The overall environmental consequence of emissions and dust for visual aesthetics will be moderate.

An overall residual impact classification for visual aesthetics for each key issue and each phase of the project is presented in Table 3.10-4.

Prediction Confidence

The baseline status of topography in the LSA is well understood, and detailed information about the future landscape and facilities to be developed in the mine area has been made available through project descriptions and closure planning. However, impact ratings are also dependent on the success of the mitigations proposed, including erosion control under challenging conditions. Overall, the prediction confidence for this assessment is considered medium.

Table 3.10-4 Residual Impact Classification for Visual Aesthetics

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

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 B, Section 6.

3.10.6 Conclusions

The mine will have moderate environmental consequences for visual aesthetics as a result of dust and emissions which may be regularly visible from outside of the LSA. Low effects will occur due to the alteration of landscape elements visible from relatively close to the mine, such as parts of the Torotorofotsy Ramsar site and populated areas along the mine access road. Negligible environmental consequences are expected due to mine facilities and lighting as these effects are expected to be very localized with mitigation applied. In general, this is a conservative assessment and the effects on most observers will be very small, as they will not find their modified views to be very different from pre-existing views. The greatest effects are likely to be on ecotourists in the Torotorofotsy area, who will have specific notions about desirable views in the area and will not expect to see stack emissions or mine landforms from the Ramsar site.

4.1 FLORA

4.1.1 Introduction

This section of the environmental assessment (EA) provides an evaluation of potential effects of the proposed Ambatovy Project (the project) on flora in the mine site 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:

- inventory each natural plant community during the wet and dry seasons to determine species richness, diversity and relative abundance;
- map and describe the baseline flora of the study areas in terms of their vegetation communities, including a consideration of structure and species composition;
- describe the current level of disturbance of each natural terrestrial community type within the study area;
- quantitatively assess the adequacy of baseline sampling;
- characterize the flora including the assessment of species endemism (including local endemics) by community type;
- select key indicator species to focus the assessment; provide the selection criteria and rationale for the choice of key species or higher indicator taxa (e.g., orchids);
- discuss the mitigation and compensatory mechanisms to be used to reduce/offset losses to flora and natural community types including forest rehabilitation activities and identification of offsite areas of similar community types that may have similar species assemblages;
- assess residual impacts to flora (including Torotorofotsy Wetlands) through mine activities including site clearing, air and water impacts for both the operations and post-closure phases of the project; and
- provide details on flora monitoring and management that include participation of stakeholders.

4.1.2 Study Area

The core area of the mine LSA for terrestrial resources encompasses the ore body complex (Ambatovy and Analamay ore bodies), and portions of the Torotorofotsy Wetlands that border the plateau and the associated watersheds (Volume A; Figure 7.2-1). The LSA also includes the proposed water intake

pipeline footprint, plus a 500 m buffer, extending 23 km west from the core area to the Mangoro River.

4.1.3 Baseline Summary

The following provides a summary of the baseline flora results in the mine 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 Classification and Mapping

Vegetation mapping was based on one-metre resolution black and white, true colour and infrared IKONOS satellite imagery acquired August 11, 2004. Classification of the vegetation types was aided by vegetation analyses and ground-truthing.

Fifteen vegetation types covering an area of 22,893 ha were identified within the mine LSA. Ten of the vegetation types are of greatest interest from a floristic and biological perspective and include:

- azonal sclerophyl tree thicket;
- azonal sclerophyl tree forest;
- azonal non-forest;
- azonal type transitional forest;
- transitional forest;
- zonal forest;
- Eucalyptus and other woodlots;
- marsh edge forest;
- marsh herbaceous vegetation cover; and
- ephemeral pond.

By comparison of the general patterns of vegetation cover with the geological makeup of the project area, it was clear that the azonal, azonal type transitional and transitional vegetation types (in addition to ephemeral pond class) corresponded closely with the ultra-basic outcrops of the Analamay and Ambatovy ore bodies on which the vegetation developed. This core area covers 2,874 ha.

4.1.3.2 Disturbances

Superimposed on the classification of the mature-phase vegetation types is an array of differential and primarily human-induced disturbances that include selective logging, heavy logging, fire and agricultural clearing. Additional disturbances in the LSA were caused as a direct and indirect result of exploration drilling activities (access roads and pads) over the past 40 years. The total amount of area disturbed from all drilling programs amounted to 63.5 ha. This project's portion of these disturbances has been estimated at 33.3 ha and represents about 1% of the azonal and transitional vegetation within the mine site areas.

4.1.3.3 Forest Structure

Forest structure tree data were collected by para-botanists in 1996, 1997 and 2004 to verify vegetation mapping and classification, and to describe stand structure, species composition and diversity characteristics among the various forests habitat within the mine LSA. Forest structure data was also used to determine if plant communities within and adjacent to the Analamay and Ambatovy ore bodies are unique from other forest vegetation types in the surrounding zonal forest landscape.

Twenty-five transects totalling more than 8 km long were established across the six main forest vegetation types of the mine LSA which included the azonal thicket, azonal forest, azonal type transitional forest, transitional forest, zonal forest and the marsh edge forest.

The most obvious differences among the forest vegetation types in the project area are structural. As a result of water stress caused by the ferricrete and ferralite substrate, trees on this substrate are short, tend to be mostly sclerophyl, and are highly susceptible to fire in the dry season. The main structural variables that differed among these forest types were canopy height, tree density, basal area and number of tree species. Comparative results among the vegetation types are shown in Volume J, Appendix 1.2.

Azonal thickets were found to be the most distinct. Not only are they clearly different from transitional and zonal forests, but also from azonal forests. Azonal thickets have trees with a shorter height, fewer stems ≥ 10 cm in diameter measured at breast height (DBH), lower basal area and few tree species ≥ 10 cm DBH compared with all other vegetation types.

Community analysis among forest vegetation types was also done on the basis of species presence/absence and abundance. Several conclusions were derived from the community analysis results:

- marsh edge forests are strongly different from both azonal thicket and azonal type transitional forests (i.e., 98% dissimilar as defined in Volume J, Appendix 1.1);
- azonal thicket forests are strongly different from both zonal forest and transitional forest vegetation types (i.e., 96 to 97% dissimilar);
- the most similar habitats, zonal forest and transitional forest are between 42 and 54% different in terms of species composition and abundance;
- azonal vegetation of Ambatovy and Analamay differ by 55 to 59%;
- within-habitat variation is less than among-habitat variation; and
- transitional forests maintain an ambiguous position between azonal and zonal forests.

4.1.3.4 Species Endemicity

After an extensive review of the available flora data for the mine site and other related sources, botanists from Missouri Botanical Gardens (MBG) have identified 127 species of concern for the mine site area. A complete list of species of concern is provided in Appendix J.1, Attachment 5, Appendix IV. Of this total, 53 species are listed in one of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) appendices, five are on the International Union for the Conservation of Nature (IUCN) list, and there are 68 others currently only known to occur in the Ambatovy/Analamay area.

Of the 127 endemic species of concern identified by MBG, 69 (Table 4.1-1) are locally endemic to the project area (Priority 1 and 2 species). Twenty-three of the 29 Priority 1 species occur within azonal vegetation types. Over half of the species collected have yet to be identified and so this work is ongoing. More surveys have been completed in 2005, and others will be completed in 2006 so that collections will be represented over an entire year to help ensure survey periods coincide with flowering periods. This additional work will complete the identification of species from within the mine footprint and from the on-site azonal protection areas. Any remaining species of concern (i.e., those not found in the on-site protection areas) will be searched for in the surrounding area, including Mantadia National Park and the proposed off-site azonal conservation area (see below).

Table 4.1-1 Numbers of Species of Concern for Different Levels of Endemism

| Endemic Status | Priority Status | Total Number of Species | Percent of Total Known Priority Species |
|-------------------------|-----------------|-------------------------|---|
| proposed mine footprint | 1 | 29 | 23 |
| project area | 2 | 40 | 31 |
| project region | 3 | 7 | 6 |
| Madagascar | 4 | 31 | 24 |
| unknown | | 20 | 16 |
| total species | | 127 | 100 |

4.1.3.5 Other Unique Flora

A survey for Aloes was carried out in 1997 and 2004 in the Ambatovy and Analamay ore body zones by a team of para-botanists. All Aloe species of Madagascar are endemic to the country, are listed in CITES appendices and many have restricted distributions; like the one occurring at Ambatovy. Because of the potential threats to the Aloe genera, a survey was done to locate as many individuals or populations as possible at Ambatovy and Analamay. Within the mine LSA, individuals and populations of Aloe were confined to ferricrete substrates in open habitat. A total of 137 individuals or populations of *Aloe leandrii* were found at Ambatovy and Analamay.

4.1.3.6 Plant Species Richness and Diversity

Species richness and diversity was assessed in several different ways. Based on the forest structure data, between 37 and 419 tree species ≥ 5 cm diameter were recorded among the forested vegetation types within the mine LSA. The highest number of species was recorded for the transitional forest type and the lowest in the marsh edge forest (Table 4.1-2). Values presented are influenced by sampling intensity.

Tree diversity at a landscape scale (i.e., within the mine LSA) was also assessed. Tree family richness in the mine LSA (trees ≥ 5 cm DBH), was estimated at 67 families. Total tree species richness was estimated at 480 species.

Table 4.1-2 Total Tree Species Richness by Vegetation Type Within Forest Plots and Subplots

| Vegetation Type | Survey Area (ha) | Cumulative Number of Tree Species by Diameter Class ^(a) | | Total Number of Tree Species |
|---------------------------------|------------------|--|----------|------------------------------|
| | | ≥10 cm | 5–9.9 cm | |
| azonal thicket | 1.16 | 104 | 61 | 165 |
| azonal forest | 3.93 | 252 | 46 | 298 |
| azonal type transitional forest | 1.12 | 131 | 83 | 214 |
| transitional forest | 2.92 | 267 | 152 | 419 |
| zonal forest | 1.57 | 255 | 114 | 369 |
| marsh edge forest | 0.12 | 37 | nd | 37 |

^(a) Number of species listed is cumulative. All species within the ≥10 cm diameter class were counted first, followed by all species in the 5 to 9.9 cm class, but not in the ≥10 cm class.

nd = No data.

Previous estimates made in the late 1990s by Phelps Dodge, which included herbaceous and other plant groups, indicated that as many as 105 families and 1,378 species occur in the mine LSA, which is more than 10 percent of the 12,000 total species estimated to be present in Madagascar, indicating the diversity of the project area.

At a global scale, plant species richness for Madagascar is estimated at 12,000 species, 1,600 genera, and 180 families, which places the island among the most biologically diverse regions in the world, along with portions of Brazil, Zaire, Cameroon and Mexico (Guillaumet 1984; Mittermeier et al. 1997).

4.1.3.7 Sampling Adequacy

Forest Structure Data Set

Species-area curves based on trees ≥10 cm DBH were developed for the zonal forest, transitional forest, azonal forest, azonal thicket, and all forest types combined. None of the species area curves were found to flatten out completely to an asymptotic level (i.e., at the peak of species richness), but some were approaching that state. The number of new species predicted to be added with each additional plot ranged between less than one and three species among vegetation types.

The biological data set of tree species presented in this EA allowed for a quantitative assessment of habitats within the mine LSA, and is, therefore, considered adequate for EA purposes.

Herbarium Samples

A more intensive inventory of flora from within the mine LSA and inclusive of trees, shrubs, herbs (including pteridophytes), vines, epiphytes (including orchids) and parasites was done by the MBG flora study team which yielded a total of 2,524 plant collections. When added to the 838 collections made by botanists who visited the Ambatovy/Analamay area at previous times during the last several decades, a total of 3,362 herbarium collections were available for analysis by the study team.

From this large collection, a total of 1,401 were sampled to date to the species level thus far (41.7%). This work has accounted for the identification of 494 species from the mine LSA. Work is ongoing to identify the remaining samples.

This represents one of the most intensive and comprehensive inventory efforts undertaken at any site in Madagascar, and provides a substantial basis for evaluating the flora of the Ambatovy/Analamay area. Additional flora surveys are planned as part of the mitigation strategy for the mine site.

4.1.3.8 Off-site Azonal Areas

An aerial reconnaissance survey took place in March of 2005 to investigate several of potential off-site azonal conservation areas, to the northeast of Ambatovy. Twenty-eight ultrabasic formations had been identified from geological data in the northern regional study area. Fourteen sites were found to lie outside currently forested habitat and were not considered further. Of the 14 sites visited, one site at Ankera, located northeast of Mantadia National Park is the best potential off-site azonal vegetation area. The fly-over showed it was not disturbed and had the general appearance of Analamay. A ground-level survey was carried out in late September 2005 to verify the presence of ferricrete and gather additional vegetation data. The general forest appearance at Ankera is characterized by a dense, stunted azonal-type forest with thick moss carpet. The flora responds to a higher rainfall-humidity regime and includes more elements of the eastern forest in contrast to Ambatovy and Analamay where the plateau flora is quite abundant. The area shows many important similarities to the project site (Volume J, Appendix 1.1). Additional flora surveys will be done at this site to determine its appropriateness as a location for off-site compensation.

4.1.4 Issue Scoping

A principal aspect in identifying environmental issues for the project involved public consultations. These meetings provided the opportunity to solicit input from local communities, conservation organizations, and government agencies at

all levels to identify environmental and social concerns. The following issues related to project-related impacts on flora were based on the outcome from the public consultation sessions, a review of previous EAs 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 are:

- loss of vulnerable, threatened or locally endemic plant species including as yet unidentified species;
- reduction of plant species diversity;
- loss or alteration of unique azonal habitats and key habitat elements;
- loss or alteration of native zonal vegetation;
- impact to wetlands (including the Torotorofotsy Wetlands) or wetlands function;
- impacts to conservation areas;
- impacts to plant health; 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 questions for flora are:

| | |
|--------------------------|--|
| Key Question FL-1 | What Effect Will the Mine Have on the Loss or Alteration of Plant Communities, Structure and Diversity? |
| Key Question FL-2 | What Effect Will the Mine Have on the Loss of Plant Species (Species Extirpation and Extinction)? |
| Key Question FL-3 | What Effect Will the Mine Have on the Introduction of Exotic and Unwanted Plant Species? |

Project-related activities anticipated to result in changes to flora include construction and operation of the mine, and site reclamation at closure. Direct losses to plant communities (including attributes of forest structure and plant diversity) will result from mine development activities. Indirect effects to flora (including reduced plant vigor, productivity and necrosis) and plant communities may occur as a result of fugitive dust and dispersion of SO₂ and NO_x, changes in hydrology and changes in water quality. Natural plant communities may also be

indirectly affected by the project from the encroachment of exotic or unwanted species. The project also has the potential to result in plant species loss (species extirpation and extinction).

These effects are primarily the result of construction and operation activities. Positive effects to flora are expected as a result of closure activities and implementation of the mitigation strategy. All project-related effects to flora may have implication for visual aesthetics, land use, fauna, human and ecological health and biodiversity. Where issues are related (e.g., loss of plant communities, community structure and plant diversity), they are analyzed and discussed together to avoid repetition. A linkage diagram for flora issues is shown in Volume H, Appendix 9.

4.1.5 Key Question FL-1 What Effect Will the Mine Have on the Loss or Alteration of Plant Communities, Structure and Diversity?

During construction and operation 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 fugitive dust and SO₂ and NO_x emissions, changes in water levels and changes in water quality.

Effects of Clearing Activities

The project footprint includes the core mine area (e.g., site facilities, roads, pits and waste rock storage areas) and water intake pipeline. Core mine site disturbances include a 50 m buffer to account for vegetation edge effects and the water intake pipeline was buffered by 25 m to account for construction impacts (i.e., spoil side and work side of pipeline).

Potential impacts to forest structure and diversity are assessed on the basis of the total change in the area of vegetation types. Forest structure is defined by the dominant strata of the vegetation type (i.e., forest, thicket or non-forest) and moisture conditions (upland or wetlands). A conservative approach was taken to assess plant diversity. All natural vegetation types were assigned a high diversity class and assessed according to loss of area.

Impact assessments were conducted for the period of construction through operation and the closure phase. It is assumed that maximum impacts will occur during the construction period and through operation, particularly during construction and the initial stages of operation when direct loss of azonal and transitional habitats will be greatest.

Effects of Air Emissions

Fugitive dust (total suspended solids) and dispersion of sulphur dioxide (SO₂) and nitrogen oxides (NO_x) were modelled for the mine site based on emissions derived from diesel-fired generators and mine fleet vehicles, and dust generated by mine vehicles as well (Climate and Air Quality, Volume B, Section 3.4). Emissions of SO₂ and NO_x were evaluated in the context of World Health Organization (WHO) guidelines for ecological effects on terrestrial vegetation. These guidelines are more stringent than air quality guidelines for human health because studies have shown that effects on vegetation from certain pollutants occur at lower concentrations (WHO 2000). A guideline value for dust is not provided by WHO or the World Bank. Thus, a qualitative assessment on the effects of dust on vegetation based on relevant literature has been provided.

Guideline values for assessing the long-term ecological effects of SO₂ and NO_x on terrestrial vegetation are provided in Table 4.1-3. The low end of the range for SO₂ (10 micrograms/m³) has been established for lichens when visible effects are first observed. The mid-range is applicable to natural forest vegetation (20 micrograms/m³) while the high end is defined for agricultural crops (30 micrograms/m³).

These guidelines are supported by research and data emanating from Europe. Therefore, there is some uncertainty as to their applicability to the project area. Adverse effects might occur below the stated guideline values. However, in the absence of data from the tropics and Madagascar, these guidelines represent the best available information.

Table 4.1-3 World Health Organization Guideline Values for the Effects of Individual Substances on Terrestrial Vegetation

| Substance | Guideline Concentration Value | Averaging Time |
|-----------------|------------------------------------|----------------|
| SO ₂ | 10 to 30 micrograms/m ³ | annual |
| NO _x | 30 micrograms/m ³ | annual |

Source: WHO (2000).

Effects of Hydrology Changes

Information from Hydrology (Volume B, Section 3.8) which includes a discussion on residual impacts as well as predicted changes in stream and wetlands water levels, were used to help assess the potential impacts to vegetation within the mine LSA. No regulatory guidelines are available for determining vegetation effects based on hydrological changes. Therefore, a qualitative approach was taken.

Effects of Water Quality Changes

Information from Water Quality (Volume B, Section 3.9) which includes a discussion on residual impacts as well as predicted changes in stream and wetlands water quality were used to help assess the potential impacts to vegetation within the mine 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 the drinking water 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, and described in Volume A (Section 7.4).

The assessment criteria used for plant communities, structure and diversity are presented in Table 4.1-4.

Table 4.1-4 Impact Description Criteria for Plant Communities, Structure and Diversity

| 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

Several mitigations are planned to reduce the magnitude, geographic extent, and duration of direct impacts from the project on flora in the mine LSA. The main areas of mitigation include:

- Creation of on-site azonal conservation areas at Ambatovy and Analamay that are representative of the key vegetation types affected by the project.
- Identification of a proposed off-site azonal protection area and conservation of this area.
- Progressive reclamation of disturbed areas using native species (improving forest structure and plant diversity).
- Construction of fencing at strategic locations adjacent to azonal protection areas, to limit damage during construction and operations.
- Development and implementation of a co-operative Forest Management Plan in a buffer area around the mine, designed to allow for sustainable forest use while maintaining biodiversity through conservation and resource use management.
- Through off-site reclamation and forest management initiatives, ensure that the total area of forest restored or protected is greater than the area disturbed by the mine.
- Provision of environmental education to mining staff and the local population to enhance and support conservation and forest management initiatives.

4.1.5.4 Results

Direct Losses to Plant Communities Within the Entire Mine Site Local Study Area

Direct losses to native plant communities as a result of the construction and operation of the mine and water intake pipeline will amount to 1,800 ha (7% of the mine LSA) (Table 4.1-5). Of this portion, within the mine LSA, 1,326 ha of azonal and transitional vegetation will be lost which represents 46% of these two vegetation classes. Of the azonal vegetation types in the mine LSA, 525 ha will be lost from the azonal forest (63% of this type), 112 ha of the azonal thicket (85%), 347 ha of disturbed azonal vegetation (83%) and 4 ha of ephemeral ponds (87%).

For zonal and other vegetation types within the mine LSA, direct losses as a result of mine clearing activities will be less than the azonal and transitional vegetation types. Losses to zonal forest will amount to 371 ha or 3% of this vegetation type within the LSA. A total of 5 ha will be lost to *Eucalyptus* and other woodlots. A total of 82 ha of the upland herbaceous vegetation cover and pasture vegetation type will be lost (2% of this class). Thirteen hectares of the marsh herbaceous vegetation/rice paddies complex will also be lost (1% of this vegetation type). Last, 3 ha of rice paddies will be directly impacted by project activities.

No direct impacts will occur within the Torotorofotsy Wetlands. Vegetation types unaffected by direct impacts from mine site construction and operations include the following:

- Marsh edge forest.
- Non-forested marsh edge.
- Non-forest slash and burn vegetation.
- Marsh herbaceous vegetation.

Table 4.1-5 Change in Vegetation Type Area as a Result of Site Clearing Within the Mine Local Study Area

| Vegetation Type | Base Case ^(a) | Impact Case | Change | Change |
|--|--------------------------|---------------|---------------|------------|
| | ha | ha | ha | % |
| Azonal and Transitional Vegetation Types | | | | |
| Azonal Forest | 826 | 301 | -525 | -64 |
| Azonal Thicket | 133 | 21 | -112 | -84 |
| Azonal Disturbed | 421 | 72 | -347 | -82 |
| Ephemeral Pond | 5 | 1 | -4 | -80 |
| <i>Azonal Vegetation Types Subtotal</i> | <i>1,384</i> | <i>396</i> | <i>-988</i> | <i>-71</i> |
| Azonal Type Transitional Forest on Gabbro | 438 | 341 | -97 | -22 |
| Transitional Forest | 1,051 | 810 | -241 | -23 |
| <i>Transitional Vegetation Types Subtotal</i> | <i>1,489</i> | <i>1,151</i> | <i>-338</i> | <i>-23</i> |
| <i>Azonal and Transitional Vegetation Types Subtotal</i> | <i>2,874</i> | <i>1,548</i> | <i>-1,326</i> | <i>-46</i> |
| Zonal and Other Vegetation Types | | | | |
| Zonal Forest | 12,527 | 12,156 | -371 | -3 |
| Eucalyptus & Other Woodlots | 831 | 826 | -5 | -1 |
| Marsh Edge Forest | 36 | 36 | 0 | 0 |
| Non-Forested Marsh Edge (Disturbed) | 195 | 195 | 0 | 0 |
| Non-Forest Slash and Burn | 2,260 | 2,260 | 0 | 0 |
| Herbaceous Vegetation Cover and Pasture | 2,709 | 2,627 | -82 | -3 |
| Marsh Herbaceous Vegetation | 102 | 102 | 0 | 0 |
| Marsh Herbaceous Vegetation / Rice Paddies | 1,012 | 999 | -13 | -1 |
| Rice Paddies | 305 | 302 | -3 | -1 |
| Village | 29 | 29 | <-1 | <-1 |
| Water | 13 | 13 | 0 | 0 |
| <i>Zonal and Other Vegetation Types Subtotal</i> | <i>20,019</i> | <i>19,545</i> | <i>-474</i> | <i>-2</i> |
| total | 22,893 | 21,093 | -1,800 | -8 |

(a) Baseline vegetation excludes exploration disturbances of which 33.3 ha is attributed to work conducted by the Project and 30.2 ha is attributed to the work of GENiM and Phelps Dodge Madagascar S.A.R.L. These disturbances totalling 63.5 ha are largely included within the loss/alteration values presented due to the overlap in areas between exploration and proposed mining.

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

Total amounts of direct impacts to vegetation are outlined above. The direct impacts related to each ore body are discussed below. These impacts are broken down for each of the two ore body zones at Ambatovy and Analamay. The impacts outlined below are not in addition to what is described above, rather, they are presented to help clarify the scope of project impacts in each of the areas represented with high proportions of azonal and transitional vegetation. Vegetation zones encompassing the azonal and transitional vegetation types within each of the ore bodies were defined for the purposes of this EA.

Direct Losses to Plant Communities at Ambatovy

Direct impacts to vegetation at Ambatovy amount to 664 ha or 51% of the vegetation within this ore body zone (a detailed breakdown is shown in Volume J, Appendix 1.2). A total of 307 ha of azonal forest will be lost as a result of project activities (70% of this vegetation type at Ambatovy). For the azonal thicket vegetation type, 58 ha will be lost (80%). A total of 77 ha of disturbed azonal vegetation (due to fire or past human influence) will be directly affected in the Ambatovy area (62% of this vegetation type). An area of 34 ha will be cleared within the azonal type transitional forest vegetation type (19%) while a total of 181 ha will be lost from the transitional forest vegetation type (39%).

Direct Losses to Plant Communities at Analamay

Direct impacts to vegetation at Analamay amount to 669 ha or 42% of the vegetation within this ore body zone (a detailed breakdown is shown in Volume J, Appendix 1.2). A total of 218 ha of azonal forest will be lost as a result of project activities (56% of this vegetation type at Ambatovy). For the azonal thicket vegetation type, 55 ha will be cleared (90%). Azonal vegetation that is currently disturbed due to fire or past human influence will be directly affected to the amount of 270 ha in the Ambatovy area (91%). An area of 63 ha will be cleared within the azonal type transitional forest vegetation type (24%). A total of 60 ha will be lost within the transitional forest vegetation type (10%).

Indirect Effects to Plant Communities as a Result of Dust and Other Air Emissions

Plant communities in the mine LSA exists today under the influence of both natural and human-induced factors. Some of the primary human factors that have directly or indirectly affected the structure and composition of local vegetation communities include logging, slash and burn agriculture, rice farming, road-building and mineral exploration activities. During mine construction and operation, vegetation may be affected further through changes in air quality as a result of mine fleet exhaust, emissions from ore processing facilities (diesel-fired generators) and dust generated from mine vehicles. These activities will disperse SO₂ and NO_x and create fugitive dust, which in turn may affect vegetation health. Spatial modelling of these air emissions has been carried out for the mine site over the life of the project and is outlined in Volume B, Section 3.4, Climate and Air Quality.

Results from the air models were considered to be conservative when applied to assessing vegetation effects. In general, a conservative approach is appropriate as it presents “worst-case” scenarios and can account for unforeseen events and

uncertainties, but in other cases may result in overstating predicted effects. Aspects of the air models that contributed to the conservative results include:

- Use of the CALPUFF model (which is inherently conservative).
- Assumption that all areas of the mine are active for the entire mine life (which they are not).
- The worst-case scenario has been presented which is the year with the highest fuel consumption and highest dust levels.

A simplified mine plan was used as a foundation of the air models. All areas slated to be mined over the life of the project were assumed to be in operation at all times. This assumption has implications for how vegetation effects are assessed because it results in a maximum zone of influence over a maximum period of years. Under the proposed mine plan, mining at Analamay is not expected to begin until after year 10 for example (Volume B, Section 2). Therefore, it is highly probable that vegetation at different locations around the mine footprint will only be subjected to project-related emissions for a portion of the mine life.

Another aspect that adds to the conservatism is the use of a worst-case scenario model representative of a year with the highest fuel consumption and greatest amounts of dust. Thus, no year is predicted to have greater values. Average values over the life of the mine will be lower. This is important as it relates to assessing the potential effects to vegetation since long-term averages may be better predictors of change than worst-case scenarios from a single-year.

Dust

Deposition of mining dust onto vegetation can result in a variety of physiological and chemical effects. These effects include reduced water content, increased conductivity, reduced chlorophyll content, reduced respiration, reduced reception of radiation or photosynthesis and reduced carbon uptake (Spatt and Miller 1981). Visible injury symptoms may occur, and in general, productivity is reduced.

There have been many studies in temperate regions on the effects of dust on vegetation. The same level of effort is lacking for research on the effects of dust on whole plant communities. Results from species studies are varied and may be compounded by other factors. As a result, no standard concentration level has been set by regulatory bodies at which dust is believed to significantly affect plant functions.

As a means of using a general guideline to base this assessment on, results from applicable studies were reviewed. One study on the effects of roadside dust on vegetation showed that reduced growth of *Abies alba* (European silver fir) was observed at concentration levels ranging between 25 to 100 micrograms/m³ (although lead and NO_x may also have been contributing factors to the observed effect) (Braun and Fluckiger 1987). The results from this study are from a single species and based in a temperate region. In the absence of a more rigorous guideline, it offers a rough basis for estimating the aerial extent and assessing the potential for vegetation effects in the mine LSA.

Certainty of vegetation effects at the mine site is speculative due to the paucity of related studies in tropical environments and none known to originate from Madagascar. However, if any effects do occur, they may be observed at certain locations within the forest structure, and on some plant forms and not others.

There is evidence to suggest that plants on the forest floor may be most susceptible to the effects of dust due to washing of the material during periods of heavy rainfall (Anthony 2001). During the wet season, there should be negligible amounts of airborne dust within the mine LSA.

The most sensitive plants according to studies from temperate regions are lichens, and in particular epiphytic lichens (Gilbert 1976). The diffuse growth form of many lichens allow for an effective means of trapping dust. As a result, epiphytic lichens can be directly affected through deposition (i.e., physical effect) or indirectly through changes in bark chemistry (Garty and Delarea 1987). Because of their sensitivity, epiphytic lichens have been used for monitoring dust fallout and effects of dust contamination (Loppi and Pirintsos 1999). Bryophytes are also capable of readily trapping dust due to their rough surface which makes them susceptible to the detrimental effects of dust as well (Richardson 1981). Epiphytic orchids (the so-called air plants that grow on tree branches) which extract moisture from the air and trap nutrients may also be susceptible to the effects of fugitive dust. There are many epiphytic orchid species in the mine LSA (e.g., *Angraecum* spp.) and many are rare or endemic to the local area.

Based on this weight of evidence, plants most sensitive to the effects of dust may be vegetation on the ground and in particular lichens, mosses and other life forms that derive some of their moisture and nutrient requirements from the air such as epiphytic orchids.

Maximum annual dust at the mine site has been modelled at concentration levels that meet or exceed a 20 micrograms/m³ guideline for a conservative measure in assessing the potential effects to vegetation. This guidance is slightly below the

lowest level observed in the roadside dust study referenced above (i.e., Braun and Fluckiger 1987). However, since plant forms such as lichens, mosses and possibly epiphytic orchids are thought to be more sensitive to dust than other forms of vegetation, the slightly lower threshold seemed appropriate for this assessment. The guideline has been used to help quantify the maximum aerial extent that the potential effects of fugitive dust on vegetation may be observed.

The aerial extent of modelled fugitive dust exceeding a concentration level of 20 micrograms/m³ is 1,118 ha (5% of the mine LSA) after removing all direct effects as a result of site clearing. The greatest amount of dust is predicted to be dispersed within the zonal forest vegetation type (853 ha; 4% of the mine LSA). Within the rarer communities (i.e., azonal vegetation types), dust is predicted to be dispersed over a maximum area of 77 ha (6% of all azonal vegetation types). This includes 43 ha of azonal forest, 8 ha of azonal thicket and 25 ha of disturbed azonal vegetation. In addition, dust may cover a maximum area of 113 ha within the azonal type transitional forest vegetation type and 73 ha within the transitional forest vegetation type.

Most of the dust is predicted to be dispersed outside of the proposed azonal conservation areas. At Ambatovy, no dust is predicted to occur within this conservation zone. Within the conservation area at Analamay, dust is predicted to be dispersed over an area of 10 ha (10% of Analamay conservation area).

Sulphur Dioxide and Nitrogen Oxides

Air emissions from mining operations that may affect vegetation health include oxides of sulphur and nitrogen. These emissions can affect vegetation health, depending on concentrations, plant sensitivity and environmental conditions (Halgren n.d.; Whitmore and Freer-Smith 1982; Freer-Smith 1983; Mansfield et al. 1987; Innes and Skelly 1988). The effects can be both short- and long-standing. Short-term exposure effects are usually restricted to a localized area and can include chlorosis or necrosis of plant tissues that may result in decreased growth rates or eventually, plant mortality. Recent evidence suggests that peak concentrations during short-term exposures (i.e., 24-hour period) have no significant effect on vegetation compared with accumulated doses (WHO 2000). Thus, only long-term potential effects have been assessed here.

SO₂

The sensitivity of plants to SO₂ fumigation is well documented; numerous single species laboratory and field studies, as well as a few whole ecosystem studies, having been completed. Long-term exposure of terrestrial ecosystems to SO₂ emissions is known to affect plant productivity directly by inhibiting plant

photosynthesis resulting in reduced productivity, vigour and health (Bell and Clough 1973).

The concentration level used to assess vegetation effects is 10 to 30 micrograms/m³ based on World Health Organization guidelines (WHO 2000). The minimum level corresponds to a level at which effects to lichens may be first observed. Woody and herbaceous vegetation are in general less sensitive to the effects of SO₂ than lichens. The guideline value for vascular plants is 20 micrograms/m³ (WHO 2000).

For this assessment, a conservative approach was taken. Areas potentially impacted by SO₂ emissions correspond with the lowest concentration guideline of 10 micrograms/m³, which in turn covers the greatest area of dispersion. Thus, this assessment focuses on the potential effects to the most sensitive plants in the mine LSA.

The predicted aerial extent of SO₂ at the mine exceeding a concentration level of 10 micrograms/m³ is 3,111 ha (14% of the mine LSA) after removing all direct effects as a result of site clearing. This dispersal zone encompasses all areas modelled for fugitive dust.

The greatest amount of SO₂ will be dispersed within the zonal forest vegetation type (2,206 ha). Within the more unique communities (i.e., azonal vegetation types) SO₂ is predicted to be dispersed over a maximum area of 325 ha (24% of all azonal vegetation types). This includes 252 ha of azonal forest, 17 ha of azonal thicket and 56 ha of disturbed azonal vegetation. In addition, SO₂ may be dispersed over a maximum area of 227 ha within the azonal type transitional forest vegetation type and 456 ha within the transitional forest vegetation type.

Included in the area values provided above, 96 ha or 100% of the Analamay conservation area occurs within the SO₂ dispersal zone of 10 micrograms/m³ or greater. A total of 14 ha (15% of the conservation area) occurs within a zone exceeding 30 micrograms/m³ of SO₂. At Ambatovy, a total of 101 ha or 48% of the conservation area occurs within the SO₂ dispersal zone or greater. A total of 6 ha (3%) occurs within a zone exceeding 30 micrograms/m³ of SO₂.

NO_x

NO_x contributes to acidification, at low concentrations it may also have a fertilizer effect (i.e., increasing growth) (Hutchinson and Meema 1987; Diekmann and Dupré 1997). However, this initial fertilizer effect may have deleterious effects in the long run, as the nitrogen accumulation exceeds vegetation uptake capabilities leading to nitrogen saturation and eutrophication

(Diekmann and Dupré 1997; Thimounier et al. 1994; Rosen et al. 1992). This scenario may be less likely to occur at the mine site, especially within azonal and transitional vegetation types because of the acidic nature of the soils (Soils Baseline, Volume I, Section 3.1).

Plants exposed to low levels of NO_x may have reduced tolerance of heat stress, insects and pathogens (Hutchinson and Meema 1987; Rosen et al. 1992; Fangmier et al. 1994). It has also been shown that continuous exposure of sensitive plants to NO_x has caused visible foliar injury (Taylor and MacLean 1970).

The minimum concentration level used to assess effects to vegetation is 30 micrograms/ m^3 based on World Health Organization guidelines (WHO 2000). The aerial extent of modelled NO_x at the mine exceeding this level is 3,876 ha (17% of the mine LSA) after removing all direct effects as a result of site clearing. This dispersal zone encompasses all areas modelled for fugitive dust and SO_2 .

The greatest amount of NO_x will be dispersed within the zonal forest vegetation type (2,551 ha). Within the more unique communities (i.e., azonal vegetation types), NO_x is predicted to be dispersed over a maximum area of 337 ha (24% of all azonal vegetation types). This includes 261 ha of azonal forest, 17 ha of azonal thicket and 58 ha of disturbed azonal vegetation. In addition, NO_x may be dispersed over a maximum area of 244 ha within the azonal type transitional forest vegetation type and 554 ha within the transitional forest vegetation type.

Included in the area values provided above, 96 ha or 100% of the Analamay conservation area occurs within an NO_x dispersal zone of 30 micrograms/ m^3 or greater. A total of 88 ha of the Analamay conservation area (92%) occurs within a zone exceeding 60 micrograms/ m^3 of NO_x . At Ambatovy, a total of 119 ha or 57% of the conservation area occurs within an NO_x dispersal zone of 30 micrograms/ m^3 or greater. A total of 64 ha of this conservation area (31%) occurs within a zone exceeding 60 micrograms/ m^3 of NO_x .

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

Hydrology

Based on results from Hydrology (Volume B, Section 3.8) there will be an increase in runoff from the mine site during construction, operation and post-closure scenarios compared with baseline conditions. This will occur as a direct result of land disturbance such as removal of vegetation, excavation and ground

compaction. Surface water will flow downstream of the mine area collection ponds within existing channels and streams to local rice paddies and marshes, including the Torotorofotsy Wetlands. The increase in surface water flow will occur primarily during the wet season. No significant change in flow during the dry season is predicted.

An increase in surface water flow is not expected to increase mean annual water levels in local area wetlands since there are no new hydrologic inputs to the mine site watersheds and groundwater deficits can be offset by releases of greater volumes of excess surface runoff through active water management. Additional water brought into the mine site from the Mangoro River by way of a water intake pipeline, will exit the mine site completely by way of the slurry pipeline.

There may be periods during the wet season when increases in surface water flow may result in water levels increases within local streams leading to wetlands, including the Torotorofotsy Wetlands. Stream water level increases are estimated to range between 1 and 9 cm during operation and post-closure periods depending upon the particular sub-basin. Stream water level increases within the Torotorofotsy drainage basin are predicted to have a negligible affect to the total inflow of water to the Torotorofotsy Wetlands (Volume B, Section 3.8). Flow levels will in part be attenuated by a runoff collection pond in the headwaters of the Torotorofotsy River. Thus, no adverse affects are predicted for the vegetation communities within the Torotorofotsy Wetlands; eastern Madagascar's largest and most intact natural marsh ecosystem.

In other local area wetlands, impacts to stream water levels are predicted to be low (Volume B, Section 3.8). In one case (i.e., the wetlands surrounding the Sahamarirana River, immediately south of Ambatovy) this translates to a stream water level increase of 8 cm during operations and 9 cm during the post-closure period. These relatively small increases in water levels at different stages of mine development and closure are not likely to have an adverse effect on wetlands fringe vegetation because this type of ecosystem is inherently adapted to wet conditions. However, depending upon the tolerances of particular wetlands species to increased water levels, there is a potential that species composition within the wetlands communities may change by favoring certain species over others. For instance, woody species are generally more sensitive to deviations of seasonal and annual hydrologic cycles than herbaceous species (Adamus and Brandt 1990). Potential effects to woody plants should not be overstated though considering that sedge and grass species dominate these wetlands ecosystems. In addition, because magnitude and probability of change to the wetlands water levels are low, any potential vegetation effect is predicted to be low as well.

Water Quality

Based on results from Water Quality (Volume B, Section 3.9) there will be an increase in the level of chromium above South African water quality guidelines for aquatic ecosystems within the Torotorofotsy Wetlands during operations as a result of mining operations. Cadmium, chromium, lead and zinc may also exceed these guidelines in other local area wetlands during operations. However, all substances will not exceed World Health Organization guidelines for drinking water (WHO 2004). Following closure, predicted maximum concentrations for all substances will return to baseline levels.

Some studies have shown that the effects of heavy metals on plants may result in physical injury and reductions in growth, physiological and biochemical activities, and plant functions (Chen 2003). In other studies, certain plant species (e.g., sedges) have shown to protect themselves from the toxic effects of heavy metals even while taking up significant quantities of substances (Erickson et al. 1996). A brief description of known toxic effects of cadmium, chromium, lead and zinc on vascular plants are as follows:

- Cadmium can be toxic to plants at soil concentrations lower than other heavy metals and is readily taken up (EPA 1981).
- Chromium may bioaccumulate in aquatic vegetation (Eisler 1986).
- Lead bioaccumulates in macrophytes including freshwater plants (Eisler 1988b; Department of Water Affairs and Forestry 1996). At elevated levels, lead can cause reduced growth and water absorption (Eisler 1988b).
- Zinc is toxic to plants at elevated levels, causing adverse effects on growth, survival and reproduction (Eisler 1993).

Over time, there is potential for plants within local wetlands, including the Torotorofotsy Wetlands, to be affected by these substances. However, the concentration levels of heavy metals entering these systems from the mine site during the operations period are predicted to be low (i.e., below drinking water guidelines) albeit higher than guidelines set for aquatic ecosystems. Taking these factors into consideration, the potential effects to wetlands vegetation during operations is expected to be low. No effects are predicted at closure.

4.1.5.5 Impact Analysis

Residual Impacts

Residual Impacts to Azonal and Transitional Vegetation Types from Clearing Activities

Activities related to construction and operation of the mine will result in direct vegetation losses, especially for rare habitat types. There will be a loss of 1,326 ha of azonal and transitional vegetation types (a total of 46% of these habitats relative to the LSA). This includes azonal forest (524 ha), azonal thicket (112 ha), disturbed azonal (347 ha), ephemeral ponds (4 ha), azonal type transitional forest (87 ha) and transitional forest (241 ha) vegetation types. The magnitude of the losses is deemed high, local in extent, of long-term duration and resulting in a high environmental consequence (Table 4.1-6). Excavation of the ferricrete and pisolite substrates that underlie these habitats will largely be irreversible.

Recognizing these facts and understanding the high importance of azonal and transitional vegetation types to supporting rare and vulnerable plant species, wildlife and biodiversity within the local area, the proponent is proposing a comprehensive on-site and off-site mitigation plan to preserve the key habitat elements of the forest landscape. In addition, the proponent will work with Malagasy authorities, communities and non-governmental organizations (NGOs) to develop a long-term sustainable forest management plan for the region surrounding the mine. Given current trends in habitat loss due to timber cutting for construction, firewood and charcoal production both within Madagascar as a whole, and locally, the proposed mitigation plan is expected to provide more positive long-term benefits to the region than if the status quo were to remain (see also Volume B, Section 5.3). The following provides greater detail on the benefits of the proposed mitigation plan.

Creation of On-Site Azonal Conservation Area

Prior to mine development, two on-site azonal conservation areas totalling 305 ha (11% of all azonal and transitional vegetation types in the LSA) will be established within the bounds of the ore body complex (Figure 4.1-1, Table 4.1-7). This initiative will be carried out in cooperation with local communities and the ministry of environment, and integrated as a component of the regional Forest Management Plan (see Volume B, Section 5.3). Establishment of these two conservation areas in each of the ore bodies helps ensure long-term representation of the major azonal vegetation types within the region. These areas will not only provide protection for vulnerable and locally endemic plants, but also provide protected rare wildlife habitat.

Table 4.1-6 Residual Impact Classification for Loss or Alteration of Plant Communities, Forest Structure and Diversity

| Component | Direction | Magnitude | Geographic Extent | Duration | Reversibility | Frequency | Environmental Consequence |
|---|-----------|-----------|-------------------|-------------|---------------|-----------|---------------------------|
| Losses Or Alterations To Plant Communities | | | | | | | |
| azonal forest | negative | high | local | long-term | irreversible | medium | high |
| azonal thicket | negative | high | local | long-term | irreversible | medium | high |
| disturbed azonal | negative | high | local | long-term | irreversible | medium | high |
| ephemeral pond | negative | high | local | long-term | irreversible | medium | high |
| azonal type transitional forest | negative | high | local | long-term | irreversible | medium | high |
| transitional forest | negative | high | local | long-term | irreversible | medium | high |
| azonal conservation areas | negative | moderate | local | medium-term | reversible | high | low |
| zonal forest | negative | moderate | local | medium-term | reversible | high | low |
| eucalyptus and other woodlots | neutral | n/a | n/a | n/a | n/a | n/a | n/a |
| marsh edge forest | neutral | n/a | n/a | n/a | n/a | n/a | n/a |
| Torotorofotsy Wetlands | negative | low | local | medium-term | reversible | high | low |
| marsh herbaceous vegetation | negative | low | local | medium-term | reversible | high | low |
| Losses Or Alterations To Forest Structure | | | | | | | |
| upland forests | neutral | n/a | n/a | n/a | n/a | n/a | n/a |
| wetlands forests | neutral | n/a | n/a | n/a | n/a | n/a | n/a |
| thickets | negative | high | local | long-term | irreversible | medium | high |
| non-forested uplands | neutral | n/a | n/a | n/a | n/a | n/a | n/a |
| non-forested wetlands | negative | low | local | long-term | reversible | medium | low |
| Losses Or Alterations To Plant Diversity | | | | | | | |
| high plant diversity | negative | moderate | local | medium-term | reversible | medium | moderate |

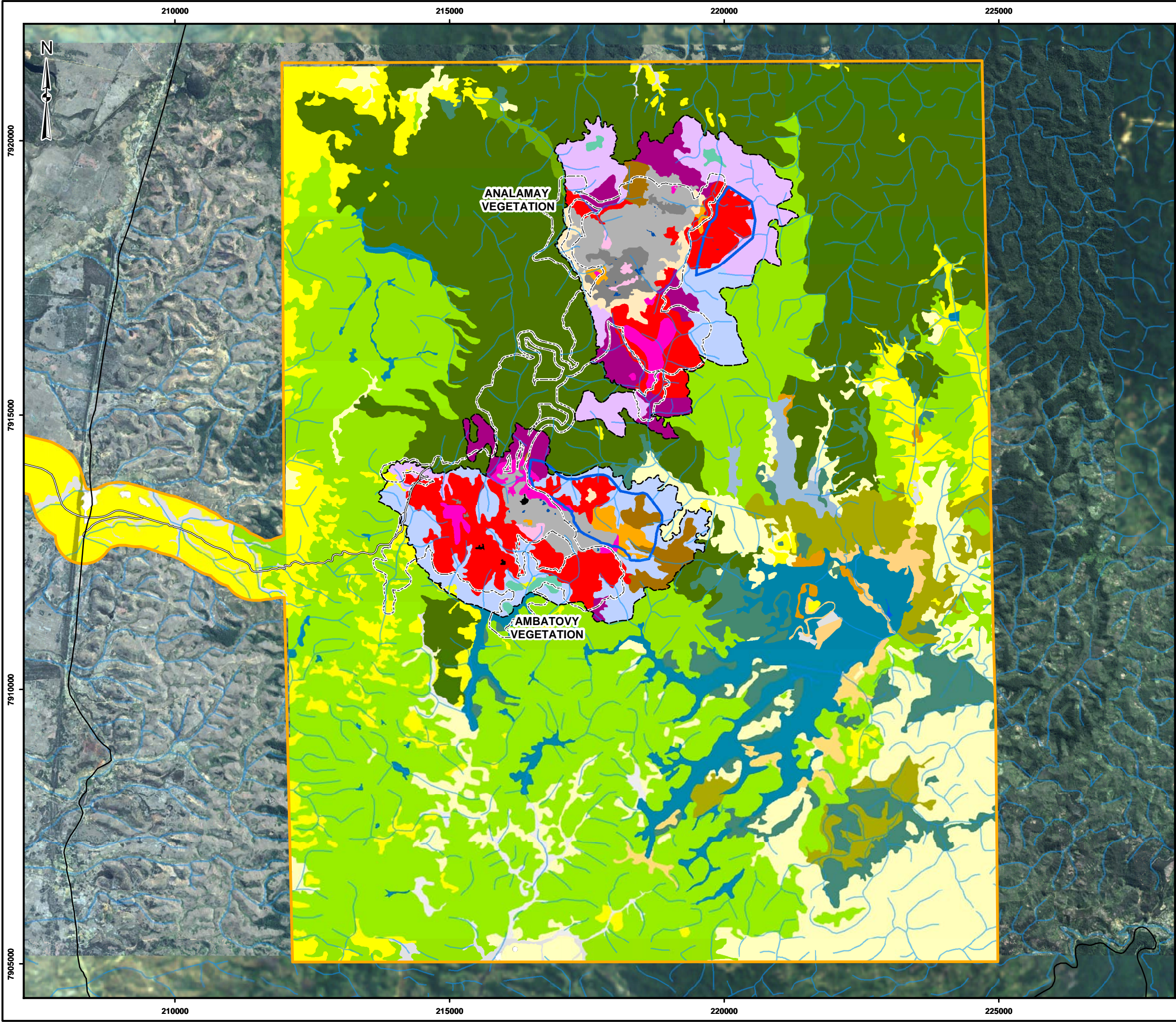
The size of the conservation area at Ambatovy is about 209 ha, which includes at least three ephemeral pools (0.18 ha), azonal vegetation (113 ha) and transitional forest (96 ha). Along some portions of the boundary separating the mine and the Ambatovy conservation area, there is an additional buffer. This area consists of

disturbed azonal vegetation amounting to about 10 ha. To the east, the conservation area abuts the forest management buffer zone, the Mantadia-Zahamena corridor and the Torotorofotsy Ramsar site.

The size of the conservation area at Analamay is about 96 ha, which includes at least three ephemeral pools (0.13 ha), azonal forest (81 ha) and transitional forest (15 ha). The conservation area is situated east of the mine and is separated by an additional azonal buffer and creek that on average amounts to a band width approximately 100 m wide. This buffer zone, if left undisturbed, will increase the effective size of the conservation area at Analamay by approximately 15 hectares.

To help protect the areas from unplanned mining activities, fencing and/or signage will be erected along specific sections of the conservation areas.

I:/2003/03-1322/03-1322-172/lrxd/Vegetation/Fig4.1-1_ConsAreas_MineSite_Veg_LEG1.mxd



LEGEND

AZONAL VEGETATION

- AZONAL THICKET
- AZONAL THICKET DISTURBED
- AZONAL FOREST
- AZONAL FOREST DISTURBED
- AZONAL FOREST BURNED
- DISTURBED AZONAL (SUCCESSION I & II)
- DISTURBED AZONAL (SPARSE VEGETATION)
- DISTURBED AZONAL (NO VEGETATION, EXPLORATION CLEARING)
- SEASONAL POND

AZONAL TYPE TRANSITIONAL VEGETATION

- AZONAL TYPE TRANSITIONAL FOREST ON GABBRO
- AZONAL TYPE TRANSITIONAL FOREST DISTURBED ON GABBRO

TRANSITIONAL VEGETATION

- TRANSITIONAL FOREST
- TRANSITIONAL FOREST (LOGGED OVER)
- TRANSITIONAL FOREST BURNED AND SLASH & BURN

ZONAL VEGETATION

- HERBACEOUS VEGETATION COVER AND PASTURE
- MODERATELY LOGGED FOREST
- MODERATELY LOGGED VALLEY BOTTOM FOREST
- HEAVILY LOGGED FOREST AND OTHER DISTURBANCES
- SLASH AND BURN FOREST
- NON-FOREST SLASH AND BURN

MARSH HERBACEOUS VEGETATION/RICE PADDIES

- RICE PADDIES
- MARSH HERBACEOUS VEGETATION / RICE PADDIES
- MARSH HERBACEOUS VEGETATION

MARSH EDGE VEGETATION

- MARSH EDGE FOREST
- NON-FORESTED MARSH EDGE (DISTURBED)

EXOTIC VEGETATION

- EUCALYPTUS & OTHER WOODLOT

OTHER

- STREAM
- ROAD
- WATER PIPELINE
- WATER
- VILLAGE
- AZONAL, AZONAL TYPE TRANSITIONAL & TRANSITIONAL VEGETATION
- MINE LOCAL STUDY AREA
- PROPOSED MINE FOOTPRINT
- PROPOSED CONSERVATION AREA

REFERENCE

IKONOS Imagery provided by Space Imaging Inc.; Captured August 11, 2004
Landsat 7 Mosaic Image; Captured April/Sept. 2001
Datum: WGS 84 Projection: UTM Zone 39S



PROJECT

AMBATOVY PROJECT

TITLE

AZONAL CONSERVATION AREAS WITHIN
THE MINE SITE LOCAL STUDY AREA



| | | | |
|-------------|-----------------|----------------|--------|
| PROJECT No. | 03-1322-172 | SCALE AS SHOWN | REV. 0 |
| DESIGN | DN 26 Jul. 2005 | | |
| GIS | TN 20 Oct. 2005 | | |
| CHECK | GJ 09 Feb. 2006 | | |
| REVIEW | DM 09 Feb. 2006 | | |

FIGURE: 4.1-1

Table 4.1-7 Azonal and Transitional Vegetation Type Conservation Areas (On-Site)

| Vegetation Type | Baseline Vegetation ^(a) | Conservation Areas ^(b) | |
|---|------------------------------------|-----------------------------------|-----------|
| | ha | ha | % |
| Ambatovy | | | |
| azonal thicket | 72 | 6 | 8 |
| azonal forest | 436 | 89 | 20 |
| azonal disturbed | 124 | 18 | 15 |
| ephemeral pond | 2 | <1 | 9 |
| azonal type transitional forest on Gabbro | 181 | 35 | 19 |
| transitional forest | 468 | 61 | 13 |
| <i>Ambatovy subtotal</i> | <i>1,283</i> | <i>209</i> | <i>16</i> |
| Analamay | | | |
| azonal thicket | 61 | 0 | 0 |
| azonal forest | 390 | 81 | 21 |
| azonal disturbed | 297 | 0 | 0 |
| ephemeral pond | 3 | <1 | 4 |
| azonal type transitional forest on Gabbro | 257 | 0 | 0 |
| transitional forest | 583 | 15 | 2 |
| <i>Analamay subtotal</i> | <i>1,591</i> | <i>96</i> | <i>6</i> |
| Ambatovy and Analamay Combined | | | |
| azonal thicket | 133 | 6 | 4 |
| azonal forest | 826 | 170 | 21 |
| azonal disturbed | 421 | 18 | 4 |
| ephemeral pond | 5 | <1 | 6 |
| azonal type transitional forest on Gabbro | 438 | 35 | 8 |
| transitional forest | 1,051 | 76 | 7 |
| Ambatovy and Analamay total | 2,874 | 305 | 11 |

^(a) Includes any pre-existing exploration disturbances.

^(b) Includes all areas within the proposed Ambatovy and Analamay conservation areas as shown on Figure 4.1-1 except 2 ha of zonal forest within the Ambatovy ore body conservation area. Area values presented include any pre-existing exploration disturbances.

Identification and Protection of an Azonal Off-Site Conservation Area

A potential azonal off-site conservation area has been identified from an aerial reconnaissance survey carried out north of the mine site (i.e., at Ankerana). A follow-up ground survey was initiated in late September 2005 to:

- Verify if the site was indeed a representative azonal outcrop similar to the mine azonal habitat.

- Collect plant samples to determine if there are floristic similarities with the Ambatovy and Analamay ore bodies.

In consideration of the potential need of this off-site area to safe guard *species of concern* from the mine site (see below), the proponent will investigate the site further through additional data collection and analysis. If this site is deemed suitable for off-site azonal compensation (Volume J, Appendix 1.1), the proponent will work with the Ministry of the Environment to discuss options for advancing this idea further.

Forest Rehabilitation

The proponent has made a commitment to support, in part, the reclamation of forested lands within the region (e.g., Zahamena-Mantadia corridor) that have been cleared in the past (Volume J, Appendix 1.2, Attachment 1). This reforestation activity would in part occur along sections of the pipeline right-of-way (RoW) (Volume C, Section 4.1). This commitment is in addition to planned reclamation efforts at the mine site (Reclamation and Closure Plan, Volume B, Section 6), the forest management buffer zone around the mine and the potential azonal off-site area approximately 80km northeast of the mine. This initiative is a positive step forward towards maintaining and enhancing the forest land base in the region and improving landscape-level vegetation dynamics over time.

Development and Implementation of a Forest Management Plan

The proponent has committed to participate in cooperative forest management and regional resource planning with the Malagasy government, communities and other stakeholders. Details of the Forest Management Plan (FMP) are outlined in Volume H, Appendix 6. Of particular interest are the benefits of the plan to maintaining the biological integrity of the azonal conservation areas. Planning support for the management of the Torotorofotsy Wetlands Ramsar site, will also be integrated with this initiative.

The two proposed on-site conservation areas do not exist in isolation. They are nested within the surrounding landscape matrix made up of transitional forest, primary zonal forest, degraded forest, cleared forest and other human-influenced land uses. The social fabric of the region is also connected to the conservation zones, in so much as local pressures on forest resources will eventually encroach upon these areas as other resources are depleted. The FMP provides a framework for sustainable forest management within the local region. This will help ensure that the integrity of the conservation areas will be maintained indefinitely. Several benefits are gained from this initiative and include:

- minimizing the amount of forest edge to the azonal conservation areas (offering buffer capacity);
- providing connectivity between the azonal conservation areas and the larger primary forest region to the northeast, which may offer secondary benefits for *species of concern*; and
- helping ensure that other forest resources (besides azonal vegetation) are available in the local region for building materials and charcoal production.

Environmental Education

Environmental education of mining staff and the local population will be supported by the proponent to enhance conservation and forest management initiatives. Staff meetings and training sessions, public information/awareness sessions and local committee meetings will be held to help disseminate information on the FMP to local workers, farmers and villagers. Many of these meetings will be organized cooperatively with the Malagasy government. The benefits of the plan will be described and discussions will take place on how everyone connected to the project and region can contribute to its success. Input from these discussions will also be fed back into the FMP for improved results. Key issues to discuss include water management, the purpose of the azonal conservation areas and objectives of the FMP. The locations of all forest management zones will be described including identifying areas allocated for sustainable resource use (e.g., land use for supplying construction timber and sources of charcoal) and restricted areas (e.g., forest grazing and herding controls near reclamation sites and the azonal conservation areas).

Residual Impacts to Azonal Conservation Areas From Air Emissions

Despite mitigation, activities related to construction and operation of the mine may result in negative changes to vegetation within the azonal conservation areas. Potential effects may include visible injury, reduced plant health, reduced growth rates and plant mortality. The most sensitive life forms (i.e., lichens, mosses) are believed to be most vulnerable to the effects of SO₂, NO_x and fugitive dust; however, epiphytic orchids which include a group of rare species at the mine site may also be sensitive to these effects. The magnitude of potential effects are expected to be smaller than predicted due to the conservative assumptions of the air models. Quantitative and qualitative factors were considered when determining the environmental consequence for this issue of concern.

Fugitive dust was conservatively estimated to affect 10 ha or 10% of the Analamay conservation area. No significant amount of dust was predicted to occur within the Ambatovy conservation area. As reported, the magnitude is rated as low when the effects from both areas are combined. The occurrence of fugitive dust will be restricted to the local area primarily in the dry season but throughout construction and operation phases (medium-term). The environmental consequence of fugitive dust on vegetation within the azonal conservation areas is predicted to be low.

Emissions of SO₂ were conservatively estimated at 96 ha or 100% of the Analamay conservation area and 101 ha or 48% of the Ambatovy conservation area based on the lowest guideline value of 10 micrograms/m³ specific primarily to lichens; most of the areas are within 30 micrograms/m³. Based on these observations, the magnitude of effects is considered moderate. The model is conservative and may overestimate effects, particularly since not all areas are mined at once and fewer vehicles are utilized than the maximum number chosen in one particular year.

The extent of the SO₂ effects will be restricted primarily to the local area and will occur during the construction and operation phases. Based on these conditions, the environmental consequence for SO₂ emissions on vegetation within the azonal conservation areas is predicted to be low.

Emissions of NO_x were conservatively estimated at 96 ha or 100% of the Analamay conservation area, and 119 ha or 57% of the Ambatovy conservation area based on a guideline value of 30 micrograms/m³ applicable to all classes of vegetation. Based on these values alone, the magnitude of effects would be considered high. As discussed above, air model assumptions were conservative. Therefore, the magnitude of NO_x effects is rated as moderate to account for these assumptions. The extent of the NO_x effects will be restricted to the local area and occur throughout the construction and operations phases (medium-term). Based on these conditions, the environmental consequence for NO_x emissions on vegetation within the azonal conservation areas is predicted to be low.

There may be additive effects resulting from fugitive dust, SO₂ and NO_x. However, there are no guidelines that deal with this scenario. Thus, the overall environmental consequence for air emissions to the azonal conservation areas is predicted to be low. To ensure the protection of the sensitive types of vegetation, a program will be implemented to monitor their health (i.e., lichens, mosses and epiphytic orchids) within the azonal conservation areas. Should the ecological integrity of these protection zones be impacted as a result of fugitive dust or SO₂ or NO_x emissions, the proponent will develop and implement plans to reduce

emission levels. Types of mitigation to be considered are outlined in the Climate and Air Quality Section (Volume B, Section 3.4).

Residual Impacts to Zonal Vegetation

A total of 371 ha of zonal forest will be impacted from mine clearing activities (3% of this vegetation type) resulting in a low-magnitude rating. The extent of effects will be restricted to the local area but will extend beyond the life of the project (long-term duration). Effects are generally considered irreversible; however, with the use of native species during reclamation, the area will exhibit similarities to pre-disturbance conditions when it reaches maturity. Based on this, the environmental consequence for clearing zonal vegetation within the mine LSA is predicted to be low.

Fugitive dust and other air emissions (SO_2 or NO_x) may also affect zonal forest vegetation. The largest of these dispersal areas (i.e., NO_x) represents 31% of the zonal vegetation type or 17% of the mine LSA. The severity of effects would be considered high if other factors and uncertainties were not considered. However, due to the conservative nature of the air model, dispersal areas are thought to be smaller and concentration levels lower than modelled. If effects do occur, they are expected to be selective. Plants have different sensitivities and tolerances to airborne substances and therefore each species or individual will react differently. Based on this, the magnitude of potential effects is predicted to be low. The extent of effects will be restricted to the local area and will occur throughout the construction and operation phases (medium-term; less so during the rainy season). As a result, the environmental consequence for air emissions on zonal vegetation is predicted to be low.

Residual Impacts to Torotorofotsy Wetlands and Other Wetlands Vegetation

Avoidance of direct effects (physical disturbance) to local area wetlands including the Torotorofotsy Wetlands complex and associated marsh edge forest will be achieved through project design.

Stream water level increases within the Torotorofotsy drainage basin are predicted to have a negligible affect on the total inflow of water to the Torotorofotsy Wetlands. This will in part be achieved through the operation of a runoff collection pond at the headwaters of the Torotorofotsy River, which will minimize changes in downstream flows. Thus, no adverse affects to vegetation are predicted for this area. Any support for vegetation monitoring would, therefore, be part of general support of management of the Ramsar site.

In other local area wetlands, the magnitude of impacts to water levels is predicted to be low. This will be achieved through active water management (see

Hydrology, Volume B, Section 3.8). The magnitude of potential impacts to vegetation (e.g., a shift in community type through changes in hydrologic regime) is also predicted to be low. The extent of potential effects will be restricted to the local area and will occur intermittently over the life of the project (i.e., during periods of the wet season). Based on these factors, hydrological changes to wetlands vegetation within the mine LSA is predicted to result in a low environmental consequence.

The magnitude of potential impacts to wetlands vegetation (including the Torotorofotsy Wetlands) as a result of changes in water quality is predicted to be low. There is the potential for cadmium, chromium, lead and zinc to bio-accumulate within wetlands plant tissue and affect vegetation growth, survival and reproduction. However, all water quality parameters are below drinking water guidelines and so the concentrations will likely be too low to cause any adverse affects.

The extent of potential effects will be restricted to 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 mine LSA is predicted to result in a low environmental consequence. Water quality monitoring will be conducted to ensure appropriate management of water quality is being attained to protect flora and fauna, and is addressed further in the water quality section of this EA. If unexpected impacts to water quality are detected, vegetation health will be monitored on a site specific basis to verify that wetlands vegetation is not being damaged.

Residual Impacts to Forest Structure

During construction and operations, there will be a high environmental consequence to forest structure due to site clearing. Forests, thickets and other vegetation will be cleared, reducing the extent and variation in landscape level forest structure. As areas are progressively reclaimed and vegetation at the mine grows and forest succession advances following closure, residual impacts to forest structure will decline.

Azonal thickets have a unique forest structure (i.e., stunted growth) that cannot be reclaimed because ferricrete soils that support this forest type will be excavated during mine construction and will not be replaced for reclamation purposes. Thus, a high environmental consequence will still remain for the thicket forest structure after closure. For all other structural vegetation types (i.e., upland forests, wetlands forests, non-forested uplands and non-forested wetlands) a neutral environmental consequence will result following closure as forests grow and develop.

Residual Impacts to Plant Diversity

During construction and operations, there will be a reduction in plant diversity within the mine LSA. Approximately 1,700 ha of native vegetation, including 1,326 ha of azonal and transitional vegetation (46% of these vegetation types), and 371 ha of zonal forest (3% of this vegetation type) will be cleared as a result of mine-related activities. Native plant communities within the mine site are considered to have high levels of diversity. Over time and as reclamation proceeds, diversity is expected to increase but not to the levels observed at baseline. Thus, the magnitude of effects is considered to be moderate. The effects will be restricted to the local mine area and will continue beyond the life of the project. Based on these factors, changes to plant species diversity are predicted to result in a moderate environmental consequence.

Prediction Confidence

Confidence in impact predictions is related to four main elements:

- Adequacy of baseline data for understanding current conditions.
- Understanding of project-related impacts on the ecosystem.
- Knowledge of the effectiveness of mitigation.
- Probability of chance events.

Many of the flora impact predictions are based on the spatial distribution of vegetation types within the mine LSA. The baseline vegetation map was developed from a combination of orthophoto interpretation and ground-truthing. Not all areas in the LSA were ground-truthed; however, the orthophotos were stratified on the basis of tones and textures representing different vegetation types, and sampling was done within most of the stratified units. Consequently, 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 high.

Mitigation to deal with the effects of vegetation removal is primarily focused on the following:

- Establishing azonal conservation areas (on-site and off-site).
- Forest management planning.
- Forest rehabilitation/land reclamation.

One assumption with regard to the on-site and off-site azonal conservation areas is that they are of sufficient size to maintain viable plant populations and are in general, ecologically sustainable. Fragmentation of the azonal habitat through mine development and pressures on local timber resources may stress these ecosystems greater than predicted. Initiatives set forth in the Forest Management Plan will address these concerns but the success of the plan will be dependent upon the cooperation of local villagers and their adherence to the primary objective of sustainability.

It is also assumed that forest rehabilitation and reclamation efforts will be successful in regenerating disturbance areas to semi-natural habitats. The understanding of forest ecosystem dynamics in Madagascar is limited at this time, which will result in reclamation development initiatives to identify the optimum plan.

Confidence of the predicted effects from fugitive dust, SO₂ and NO_x, is low. With respect to the literature, there is contradictory evidence for example on the direction of effects from NO_x on vegetation (e.g., both positive and negative effects have been observed in studies). Furthermore, vegetation effects guidelines are based on data derived from temperate regions. Therefore, there are inherent uncertainties when trying to extrapolate results and guidelines derived from other regions of the world. Additional uncertainties can be attributed to the air emission models as outlined in the Climate and Air Quality Section (Volume B, Section 3.4). Thus, prediction confidence of residual impacts for fugitive dust, SO₂ and NO_x on vegetation is considered to be low.

There are also 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. The effectiveness of the water management plan is also a significant factor in the confidence of the predicted effects to vegetation. However, the assessment made in the EA regarding effects of water is based on conservative assumptions. Thus, prediction confidence of residual impacts to wetlands is considered to be medium.

Monitoring

Monitoring programs will be implemented to ensure the adequate functioning of the protection systems. These programs will:

- Ensure that objectives of the forest management plan within the azonal conservation areas are being met.

- Ensure that air emissions, including dust, are not detrimental to sensitive vegetation health and plant community composition (such as lichens, mosses and epiphytic orchids) in the azonal conservation areas.
- Verify that water quality and water levels entering the Torotorofotsy Wetlands and other watersheds are having no detrimental effects.
- Monitor the effectiveness of the reclamation plan to ensure that erosion control measures are working effectively and vegetation cover is maintained.
- Monitoring in the off-site azonal protection area will act as a control for on-site protection areas.

4.1.5.6 Conclusions

Despite mitigation, activities related to construction and operation of the mine will result in a high environmental consequence to azonal and transitional vegetation types, which includes azonal forest, azonal thicket, disturbed azonal, ephemeral ponds, azonal type transitional forest and transitional forest within the mine LSA. The effects will be local in extent and irreversible.

Effects of the project on vegetation structure were also assessed. A negligible environmental consequence was assigned to upland forests, wetlands forests, non-forested uplands and non-forested wetlands. This will be achieved through project design and avoidance or through reclamation to a forested structural state. Due to the unique structure of the azonal thicket vegetation type associated with ferricrete substrate, a high environmental consequence will still remain for this type of stunted forest after closure.

Native plant communities within the mine site are considered to have high levels of diversity. Over time and as reclamation proceeds, diversity is expected to increase but not to the levels observed at baseline. Thus, changes to plant species diversity are predicted to result in a moderate environmental consequence. The effects will be restricted to the local mine area and will continue beyond the life of the project.

Conservation areas proposed for the Analamay and Ambatovy areas are meant to preserve a portion of the azonal and transitional vegetation habitats that exist above the ore body complex. These areas will not be entirely isolated from pressures for timber and firewood, nor will they be outside of the air emissions dispersal area. Despite this, the effects of SO₂ and NO_x emissions and fugitive dust from the mine (and all other areas within the mine LSA) are predicted to result in a low environmental consequence to vegetation health. In addition, the forest management plan will serve as a template to direct forest resource

extraction activities away from the azonal conservation areas and towards other areas designated in the region for this purpose.

Hydrologic changes resulting from construction, operation, and closure of the mine is predicted to result in a negligible environmental consequence to the Torotorofotsy Wetlands. For other wetlands in the local study area, predicted changes in vegetation health and species composition will be low resulting in a low environmental consequence.

Water quality changes to wetlands vegetation (including the Torotorofotsy Wetlands) are predicted to result in a low environmental consequence. There is the potential that a number of heavy metals entering the wetlands from mine site runoff will bio-accumulate within plant tissue, affecting growth, survival, and reproduction. However, all water quality parameters are below drinking water guidelines and most parameters are consistent with current baseline conditions, therefore the parameters are likely at concentrations too low to cause any adverse affects.

The primary types of mitigation proposed will focus on:

- Establishment of two on-site azonal conservation areas and one off-site azonal conservation area.
- Progressive reclamation using native species.
- Development and implementation of a co-operative Forest Management Plan in a surrounding buffer zone.
- Forest renewal initiatives and development of environmental education programs.

4.1.6 Key Question FL-2 What Effect Will the Mine Have on the Loss of Plant Species (Species Extirpation or Extinction)?

Plant species diversity in tropical environments such as Madagascar is extremely high (close to 13,000 species [CI 2005]). In addition, 89% of the plant species are endemic to the country. This diversity and uniqueness is related to the geological history of the island, differences in soil and bedrock types, elevation, meteorological patterns and clines, and geographical range across more than 13 degrees of latitude (Gautier and Goodman 2003). Considerable species heterogeneity in Madagascar even occurs within continuous forested areas at the same elevation Capuron (1951). It follows that loss of natural habitat is one of the most important factors affecting species extinction (Fahrig 1997).

Loss of habitat results in reduced population sizes and distribution ranges which increase the risk of extinction (Burkey 1995). Thus, removing rare habitat at the mine site during construction and operation phases may impact plant species diversity and without mitigation could cause species extirpation or extinction. However, based on recent aerial and reconnaissance ground surveys north of the mine, other off-site azonal areas appear to exist in the region and may contain similar rare species.

4.1.6.1 Assessment Methods

Flora surveys and associated research were carried out by MBG to develop a list of *species of concern* to consider in the design and development of the mine project. Priority 1 species are only known to occur within the mine footprint and nowhere else in the world. Priority 2 species are only known to occur with the mine LSA. These categories comprise the most important species to consider in this assessment as their existence is directly threatened by the project.

The potential for species extirpation or extinction is a serious matter. Since this possibility exists, it automatically rates the potential impact as a high environmental consequence unless mitigations are effective at eliminating this threat.

4.1.6.2 Assessment Criteria

The assessment criteria used for species loss are presented in Table 4.1-8.

Table 4.1-8 Impact Description Criteria for Species Loss

| Direction | Magnitude | Geographic Extent | Duration ^(a) | Reversibility | Frequency |
|---|---|--|--|----------------------------|--|
| neutral: no change in species extinction negative: a loss of species | negligible: no species extinction high: one or more species become extinct | 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) Duration of exposure to risk of species loss.

4.1.6.3 Mitigation

Several mitigations will be implemented to reduce or eliminate the possibility of species extirpation or extinction due to project activities. The main types of mitigation include:

- Creation of on-site azonal conservation areas at Ambatovy and Analamay representative of the rare vegetation types affected by the project (e.g., azonal vegetation) and providing protection for vulnerable species.
- Identification and proposed protection of an off-site azonal conservation area.
- Development and implementation of a buffer zone Forest Management Plan designed to allow sustainable forestry while maintaining biodiversity through conservation and resource use management.
- Continue to conduct on-site and regional flora surveys to reduce or eliminate the list of species of concern.
- In conjunction with local flora specialists, establish species-level conservation programs including identification, transplantation and cultivation of any remaining species of concern before construction begins.
- Provide environmental education to mining staff and the local population to enhance and support conservation and forest management initiatives.

4.1.6.4 Results

As of October 2005, there are a total of 69 Priority 1 and 2 plant species that are only known to occur within the mine site footprint (Priority 1a and 1b) and mine LSA (Priority 2a and 2b) within the last 20 years (Table 4.1-9). There is still ongoing identification of close to 2,000 herbarium samples from the mine LSA (on and off the footprint). Once identified, these results will be updated. However, limited data is available outside the LSA for true comparative purposes especially for azonal vegetation on ultra-basic outcrops.

Table 4.1-9 Endemic Species of Concern in Priority Categories 1a, 1b, 2a and 2b Found Within the Mine Site Project Area

| Priority Category | Description | Number of Species |
|-------------------|--|-------------------|
| 1A | rare or restricted distribution and only found within the mine site footprint | 27 |
| 1B | inadequate sampling but only found within the mine site footprint | 2 |
| 2A | rare or restricted distribution and only found within the mine LSA, outside of the footprint | 37 |
| 2B | inadequate sampling but only found within the mine LSA, outside of the footprint | 3 |

4.1.6.5 Impact Analysis

Residual Impacts

Residual Impacts to Species Loss

As stated above, without mitigation to deal with uncertainties about the true distribution of plant species only known to occur within the mine footprint or mine LSA, species extirpation or extinction remains a high risk. As a result the proponent's mitigations are aimed to ensure that viable populations of all *species of concern* are secure during construction, operations and following closure of the mine, resulting in a neutral effect (Table 4.1-10).

Table 4.1-10 Residual Impact Classification for Loss of Plant Species

| Component | Direction | Magnitude | Geographic Extent | Duration | Reversibility | Frequency | Environmental Consequence |
|---------------|-----------|-----------|-------------------|----------|---------------|-----------|---------------------------|
| plant species | neutral | n/a | n/a | n/a | n/a | n/a | n/a |

n/a = Not applicable (neutral impacts not classified)

Several mitigations applicable for the protection and enhancement of vulnerable species have been listed above. Below, additional mitigation details are provided that will help ensure *species of concern* are either de-listed or secure.

Identification and Protection of an Azonal Off-Site Azonal Conservation Area

A potential azonal off-site conservation area has been identified from an aerial reconnaissance and ground-level survey conducted north of the mine site (i.e., Anker). The next step is to conduct flora surveys identifying Priority 1 or

2 species in anticipation to declassify a portion of the species from local to regional endemics. Should the results of the detailed ground survey show that the site offers adequate protection for in-situ Priority 1 or 2 species (i.e., the same vulnerable species found only within the Ambatovy and Analamay ore bodies), the proponent will then propose that this site be established as a conservation area.

On-Site and Regional Flora Surveys

Additional flora surveys are being completed within the ore bodies and associated on-site azonal protection areas, and later within the local and regional areas to address the issue regarding species of concern. The purpose of the flora surveys will be to:

- Locate populations of species of concern outside of the mine footprint and within designated protected areas in order to remove such species from the priority listings (or declassify from local to regional endemic).

Protected areas offer the best prospects for the continued long-term survival of rare and endangered plant species since development and human-induced pressures are restricted or curtailed. To ensure the continued survival of species known only known to occur within the Ambatovy/Analamay area (i.e., Priority 1 and 2 species of concern) but outside of the conservation areas, the preferred mitigation option is to locate and conserve at least one population (or several populations, if at all possible) in-situ, within a zone explicitly designated for conservation. Secondly, *safe sites* located away from the proposed mining area and managed specifically for ex-situ conservation is proposed. This mitigation is outlined in more detail below.

Establishment of a Species-Level Conservation Program

If all Priority 1 and 2 species are not secured through means of on-site or off-site conservation areas, the affected species populations will be maintained (indefinitely into the future) at *safe sites* located away from the proposed mining area and managed specifically for ex-situ conservation. *Safe sites* may be represented within the conservation areas as defined above (see on-site and regional flora surveys). This approach may entail transplanting vulnerable species directly from the mine site to the *safe sites*.

Aloe leandrii for example, may be suited for this approach. Many individuals could be transplanted from their current locations, of which the majority occur within the mine footprint and in open-canopied and disturbed azonal habitat, to similar habitat within the azonal conservation areas.

Through discussions with local and regional experts the proponent will coordinate a conservation program targeting vulnerable species to be salvaged, cultivated and propagated at an on-site flora sanctuary and subsequent distribution into suitable conservation areas.

Prediction Confidence

There is a high amount of uncertainty regarding aspects of the potential effects of the project on species loss. Currently, less than half of collected plant species have been identified, and therefore there is the potential that additional new species will be discovered, increasing the risk of species loss and lowering the prediction confidence. However, additional identifications may also reduce the list of species of concern.

All organisms, plants included, are part of a functioning ecosystem, and as such are often dependent on animals at critical stages of their life cycle (such as pollination, seed/fruit dispersal, etc.). Many plant species (but by no means all species) can be successfully grown outside their natural ecosystem, at least for a period of time, provided the right environmental conditions are provided in a constant, reliable manner. It is very difficult, however, to be absolutely certain that a species will be able to survive and reproduce for multiple generations under artificial circumstances, no matter how carefully controlled and monitored they are.

The chance of a catastrophic event (e.g., extreme cyclone or fire) causing a significant loss of habitat within the azonal conservation areas is considered to be low. The possibility exists that such an event could occur, increasing the risk of species loss. However, our ability to predict catastrophic events is poor.

Monitoring

A vegetation monitoring program will be implemented to ensure that protection of vegetation health and survival is being achieved. These programs include:

- Monitoring the vegetation health of vulnerable species in the azonal conservation areas to ensure their continued survival.
- Monitoring vulnerable species that have been transplanted to ex-situ *safe sites*.

4.1.6.6 Conclusions

Through the implementation of extensive mitigation measures, *species of concern* (Volume J.1, Attachment 5) are predicted to be secure from extirpation

and extinction during construction, operations and following mine closure resulting in a neutral effect. Mitigation and monitoring programs required to ensure the long-term survival of these species includes:

- Identification and protection of an off-site azonal conservation area.
- Continuing on-site and regional flora surveys.
- Establishment of species-level conservation program.
- Monitoring vulnerable species in the azonal conservation areas.
- Monitoring vulnerable species that have been transplanted.

4.1.7 Key Question FL-3 What Effect Will the Mine Have on the Introduction of Exotic and Unwanted Plant Species?

Roads (and mines by default) contribute to increases in the spread of exotic species (Trombulak and Frissell 2000). Edge effects from forest clearings increases light which in turn increases the density of species that prefer high light levels such as disturbance-adapted or early successional species (Mehrhoff 1989). Exotic or unwanted (weedy) species typically increase along disturbed forest edges as a result of preferred habitat conditions, stressing or removing native species, and providing a contact zone for dispersal (Trombulak and Frissell 2000).

4.1.7.1 Assessment Methods

Assessing the potential effects of the mine on exotic and unwanted species (i.e., weeds) populations was carried out in a qualitative manner.

4.1.7.2 Assessment Criteria

The assessment criteria used for exotic and unwanted species are presented in Table 4.1-11.

Table 4.1-11 Impact Description Criteria for Exotic and Unwanted Plant Species

| Direction | Magnitude | Geographic Extent | Duration | Reversibility | Frequency |
|--|--|--|---|----------------------------|---|
| neutral: no change in exotic and unwanted species negative: a change in exotic and unwanted species | negligible: no measurable effect on exotic and unwanted species low: low amounts of exotic and unwanted species moderate: moderate amounts of exotic and unwanted species high: high amounts of exotic and unwanted species | 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 |

4.1.7.3 Mitigation

The main areas of mitigation include:

- Implementation of an invasive species control program.
- Reclamation.
- Environmental education.

4.1.7.4 Results

There is a high potential for the spread of weeds or unwanted species within the mine site, reclamation areas and azonal conservation areas. Currently, heliophytic (sun-adapted) vines exist within the mine site that may permanently alter species succession by spreading into the adjacent azonal and zonal forests. As vegetation is cleared during the construction phase, areas become susceptible to invasion by unwanted species due to full sun conditions and the lack of competitors. Vehicle traffic will increase sharply within the mine area as construction begins and will continue at high levels during operations. Vehicles provide a vector to transport weeds from areas on and off-site into new areas as they are become cleared.

4.1.7.5 Impact Analysis

Residual Impacts to Exotic and Unwanted Species

Over the life of the mine, it is expected that exotics and unwanted plant species will invade reclaimed areas and forest edges. The degree to which these species

take hold and spread will be dependent upon the effectiveness of the mitigations proposed. Aggressive control measures will be used to eradicate the species as soon as they are discovered. Initially, unwanted species may be difficult to recognize as troublesome since they may be native species. In certain cases, a species may become prominent in an area, which may be part of a normal successional pathway. In other cases, a species may simply choke out others, reducing diversity and limiting succession.

Control measures planned cannot eliminate unwanted species totally, and therefore, a low negative environmental consequence is predicted (Table 4.1-12).

Table 4.1-12 Residual Impact Classification for Exotic and Unwanted Plant Species

| Component | Direction | Magnitude | Geographic Extent | Duration | Reversibility | Frequency | Environmental Consequence |
|----------------------------------|-----------|-----------|-------------------|-------------|---------------------------|-----------|---------------------------|
| exotic or unwanted plant species | negative | low | local | medium-term | reversible ^(a) | medium | low |

^(a) Depending on species.

Outlined below are several mitigations to help ensure that the spread of exotic or unwanted plant species is minimized.

Implementation of Invasive Species Control Program

During construction, operation and closure, control measures will be defined and used to rid exotic and unwanted (weedy) species in disturbed, reclaimed and conservation areas.

Reclamation

Mine site habitat rehabilitation will incorporate the use of native species during closure through on-site planting initiatives. Details of the mine site reclamation program are provided in Volume B, Section 6.

Environmental Education

Environmental education of the local population will be supported by the proponent and conducted cooperatively with the Malagasy Government to enhance the support of conservation initiatives. The education program will include various topics, such as water and soil management, land use planning and reclamation. One example of a specific topic is herding controls near reclamation sites to limit the spread of weedy species and to meet target growth objectives of desired native species on-site.

Prediction Confidence

The general behavior of invasive species is well understood. Additional information on specific weeds that may be found on-site will need to be gathered as part of the mitigation plan. This information will include species' preferred habitat, invasive strategies, means of propagation and eradication methods.

Monitoring

A monitoring program will be implemented to ensure suitable levels of control are being maintained for exotic and unwanted species. This program includes:

- Monitoring the effectiveness of exotic and unwanted species control measures within rehabilitating areas and along azonal forest edges where such species may encroach.

4.1.7.6 Conclusions

During construction and operation, a low environmental consequence is predicted for the introduction and spread of exotic and unwanted plant species. The effort to control these species will include:

- Implementation of invasive species control program.
- Active reclamation.
- Environmental education and consultation with stakeholders, including local communities.
- Monitoring the effectiveness of exotic and unwanted species control measures.

4.2 FAUNA

4.2.1 Introduction

This section presents the Environmental Assessment (EA) for the effects of the mine on fauna, including potential impacts on rare and locally endemic species, faunal movement and faunal health. The assessment addresses the Ambatovy Project (the project) Terms of Reference and issues raised during consultation.

The faunal EA includes a baseline summary of survey results for key taxa and a summary of key issues. For each identified issue, the following topics were addressed:

- evaluation of potential impact pathways;
- assessment methods;
- assessment criteria;
- mitigation;
- impact analysis;
- residual impact classification;
- prediction confidence; and
- monitoring.

A summary of the main impacts as they relate to key species and habitats is provided.

4.2.2 Study Area

The core area of the mine site local study area (LSA) for terrestrial resources encompasses the ore body complex (Ambatovy and Analamay ore bodies), portions of the Torotorofotsy Wetlands that borders the plateau and the associated watersheds (Figure 7.2-1, Volume A). The LSA also includes the proposed water intake pipeline footprint, plus a 500 m buffer, extending 23 km west from the core area to the Mangoro River.

4.2.3 Baseline Summary

4.2.3.1 Introduction

The mine LSA was surveyed for a variety of taxa in 1997, 2004 and 2005. The study area was found to have faunal biodiversity levels similar to or higher than the surrounding zones. In global terms, this is a high biodiversity area with very high levels of endemism.

4.2.3.2 Methods

Vegetation Classification

In each local study area, remote sensing data were used to produce spatial land cover maps. Details of the methods used to determine land cover classifications for each study area are provided in Volume J (Appendix 1.1).

Faunal Surveys

Baseline surveys for mammals, birds, reptiles, amphibians and insects were completed within the mine LSA by teams of Malagasy and international scientists during the wet season in early 1997 and 2004. Additional surveys were conducted for birds in late 2004 and for reptiles and amphibians in late 2004 and early 2005. Emphasis was on conducting studies during seasons best suited to documenting species presence, which was mainly the wet season. In addition, bird studies continued in the Torotorofotsy Wetlands through the 2004 dry season, to fully document the seasonal importance of the wetlands. The methods employed in each study are summarized in Volume J, Appendix 2.1.

Observations were recorded in each of the three key areas of the LSA: Ambatovy, Analamay and Torotorofotsy. Survey locations in the Ambatovy and Analamay areas were focused in the azonal and transitional habitats, with a few locations in the nearby zonal forest. In the Torotorofotsy area, surveys focused on the marsh habitat, with some locations in the surrounding zonal forest.

4.2.3.3 Results

Vegetation Classification

Detailed vegetation types were identified for the mine LSA (see Volume J, Appendix 1.1). These vegetation types were pooled into seven main vegetation classes (habitats) for the faunal analysis as these categories describe the broad vegetation classes in the mine LSA. The habitats are as follows:

- azonal sclerophyll tree forest and tree thickets;
- transitional forest;
- zonal forest;
- marsh edge forest;
- marsh;
- ephemeral pools; and
- other (exotic vegetation or highly disturbed habitats).

General Fauna Results

Amphibians and Reptiles

Sixty-seven amphibian species and 60 reptile species were recorded during the herpetological surveys in the Ambatovy, Analamay, and Torotorofotsy areas of the mine LSA (Volume J, Appendix 2.1). This is a very high diversity for these taxa, exceeding species richness values reported for Andasibe-Mantadia National Park (Amphibians: 36, Reptiles: 39; Parcs Nationaux Madagascar 2000), although surveys in this park were not exhaustive. Over 98% of these species are endemic to Madagascar (only two species are not endemic *Ptychadena mascareniensis* and *Pelusios subniger*). During all surveys for this project four new species were identified in the mine LSA: *Plethodontohyla* sp. nov., *Boophis* sp. nov., and *Liophidium* sp. nov. 1 and 2. Formal taxonomic descriptions and clarifications are underway. Two of these species are thought to be endemic to the LSA: *Liophidium* sp. nov. 1 and *Boophis* sp. nov. Both of these species were, however, observed only in 1997 surveys.

Significant observations including local and regional endemics, rare species and species restricted for trade are summarized in Volume J, Appendix 2.2, Table 1. Five species are regionally endemic and cause for conservation concern. Three of these species currently are not officially classified. Two species are new to science and have been found only in the Ambatovy area. Although discovery of individuals of these species outside the project area is likely, they must be considered endemic to the project area until found elsewhere. These locally endemic species will be put at higher risk of extirpation or extinction if habitat loss increases. Six of the species observed in the mine LSA are listed on the International Union for the Conservation of Nature (IUCN) Red List and 21 species are listed by Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

Species were summarized by the areas (Ambatovy, Analamay, Torotorofotsy) and habitats in which they were observed (Volume J, Appendix 2.1). Habitat specialists, i.e., species only observed in one area or habitat, were also identified.

The summary of habitat specialists is provided in Volume J, Appendix 2.2, Table 2. Species accumulation curves were calculated for the LSA and by habitat and suggest that additional species may be found in each habitat, but overall few more species are predicted to occur in the LSA.

Birds

During the bird surveys in the Ambatovy, Analamay, and Torotorofotsy areas of the mine LSA, 113 species were recorded (Volume J, Appendix 2.1). Of these, there are 63 endemic species and 27 endemic subspecies. This is a very high diversity for these taxa, comparing well with numbers known from Andasibe-Mantadia National Park (112, Parcs Nationaux Madagascar 2000). Forty-seven species were only recorded in one of the two survey years.

Significant observations including local and regional endemics, rare species and species restricted for trade are summarized in Volume J, Appendix 2.2, Table 1. The most significant species identified in the study area is the endemic slender-billed flufftail (*Sarothrura watersii*), which is only known from one other location in Madagascar and is facing severe habitat loss. Marsh habitat is severely threatened in Madagascar due to conversion of marsh into irrigated rice. Fifteen of the species observed in the mine LSA are listed on the IUCN Red List and 16 species are listed by CITES.

Lemurs

Nine lemur species were recorded during the lemur survey, including three diurnal species (*Indri indri*, *Propithecus diadema diadema* and *Eulemur rubriventer*), two crepuscular species (*Eulemur fulvus fulvus* and *Haplemur griseus griseus*) and four nocturnal species (*Avahi langier*, *Lepilemur sp.*, *Cheirogaleus major* and *Microcebus cf. rufus*). At least two species of *Lepilemur* occur in the eastern rainforests. The taxonomy of this genus is currently under revision and as such this species is listed as *Lepilemur sp.* with the understanding that it is likely either *Lepilemur mustelinus* or *Lepilemur microdon*. One species expected to occur in the area was not observed: *Daubentonia madagascariensis*, but this is a difficult animal to observe and is found in almost all Malagasy forests. Conspicuous signs of an additional very rare species, the greater bamboo lemur (*Prolemur simus*), have been observed in the zonal forests surrounding Torotorofotsy but the presence of this species has not yet been verified.

All lemur species are endemic to Madagascar and seven of the nine lemur species observed in the mine LSA are listed on the IUCN Red List Volume J, Appendix 2.2, Table 1. All lemur species are listed in Appendix I of CITES.

Small Mammals

Eighteen species of small mammals were recorded during the baseline surveys, 16 of which are endemic to Madagascar (Volume J, Appendix 2.1). Three additional unidentified *Microgale* species were recorded bringing the total number of terrestrial and arboreal small mammal species to 21. Species accumulation curves (Volume J, Appendix 2.1) indicate that few species were undetected and that observed species richness is greater than that recorded in Andasibe-Mantadia National Park (16, Parcs Nationaux Madagascar 2000).

One of the species (*Microgale* sp. A) was previously identified, however *Microgale* sp. B does not meet the measurement statistics of any described *Microgale* and may represent a new species. Two species identified during the surveys are IUCN listed (Volume J, Appendix 2.2, Table 1) but none are listed by CITES.

The most commonly observed species were *Microgale cowani*, *Microgale longicaudata*, *Microgale talazaci* and the introduced *Suncus murinus* and *Rattus rattus*. *Rattus rattus*, which was not observed in Analamay area in the 1997 surveys, was observed in all areas in 2004.

Bats

Six bat species and one genera were detected during the bat survey in the mine LSA (Volume J, Appendix 2.1). A total of 186 point counts detected bats on 69% of occasions. Molossid bats and *Eptesicus matroka* were the most frequently detected while *Myotis goudoti* was only recorded at two survey locations. The mine LSA is not a site of national importance for bats in Madagascar but species richness is similar to that reported for Ranomafana National Park (8; WildMadagascar 2000). Although at least six bat species were recorded, the detection rate was rather low. This is most likely to be a reflection of the lack of roost sites available in the area for vespertilionid bats. The most important habitat for bats was the marsh edge habitat in the Torotorofotsy Wetlands.

Myotis goudoti is the only bat species detected during the survey that is listed on the IUCN Red List and is listed as Near Threatened (Table 4.2-1). Although the IUCN vulnerable *Myzopoda aurita* was not detected, the habitat is potentially suitable and it has been recorded within similar habitat 20 km from the study site at Andasibe-Mantadia National Park (Russ et al. 2001). None of the species detected is listed by CITES.

Ants

In the mine LSA, 75 ant species were recorded (Volume J, Appendix 2.1). Further determination of the Formicidae species sampled is underway.

Significant observations including local and regional endemics and rare species are summarized in Volume J, Appendix 2.2, Table 1. An important discovery was the observation of colonies of *Pilotrochus* at Ambatovy. This endemic genus has not been observed since 1975 near Moramanga, despite widespread surveys. The discovery in the Ambatovy area of the LSA suggests that *Pilotrochus* is endemic to the local area. In addition, six regional endemics and five other rare species were observed in the LSA (Volume J, Appendix 2.2, Table 1). One *Pheidole* sp., *Pheidole oculata*, is IUCN listed as vulnerable. As there were six unidentified *Pheidole* spp. recorded, there is a possibility that one was *Pheidole oculata*. No ant species are listed by CITES.

Butterflies and Moths

To date, 11 families and 142 species of Lepidoptera have been identified from the species captured in the field, most (103) of which are from the Family Papilionoidea (Volume J, Appendix 2.1). In total, 131 butterfly species have been identified. The mine LSA butterfly community has a particularly diverse assemblage of *Nymphalidae* and *Hesperiidae*, with 76 and 32 confirmed species, respectively. At least 24 more potential species currently classified to the genus level require further classification. The still increasing species accumulation curve for the LSA supports the finding that additional species would still be observed if further studies were conducted (Volume J, Appendix 2.1).

A summary of key observations including rare species and key sightings is provided in Volume J, Appendix 2.2, Table 1. These observations suggest that this area is a hotspot for butterflies. The species specialists consider the detection of the rare *Hovala* 2 to be the most significant butterfly observation. There are less than 10 known specimens of this undescribed *Hovala*, which appears localised to the Analamazaotra region. The IUCN vulnerable species, *Papilio mangoura*, was recorded although this has not yet been confirmed from the taxonomic analysis. No lepidopteran species are listed by CITES.

Rare or Unique Habitats

The Biodiversity Assessment (Volume B, Section 4.4) assesses the impacts to habitats that support key faunal and floral species. Habitats were rated based on key features, including the following measures for fauna:

- species richness for terrestrial vertebrates and invertebrates;

- number of each priority species (level of endemism);
- number of habitat specialists; and
- number of endangered, threatened and vulnerable fauna species.

Species richness was based on the total number of observed species from all field sampling programs. Of these species, those only recorded in one habitat were considered specialists to that habitat. The level of species endemism was determined as per the literature and species specialists (Volume J, Section 2.1) and species conservation and protected status was based on IUCN and CITES listings, respectively. These scores, along with ratings for other biodiversity measures, were totalled to determine the habitats with the highest biodiversity potential. Azonal and transitional habitats scored the highest (Volume J, Section 4.1).

There are various sensitive or valued ecosystem components in the Ambatovy region. The valued components include the azonal forests, rivers as headwaters, ephemeral pools and the Torotorofotsy Wetlands.

The azonal and transitional forests are unique and may occur in only a few areas in Madagascar. In the biodiversity assessment, they were rated the highest (Volume J, Section 4.1). Although the azonal forests of Ambatovy tend to contain slightly lower numbers of faunal species (alpha diversity) than other forests at similar altitudes in eastern Madagascar, they are extremely valuable as potentially unique ecological zones and the biodiversity analysis indicates that this habitat is of particular interest.

The ephemeral pools on the Ambatovy and Analamay plateaus are rare due to several factors. First, their location on the ferricrete creates special hydrologic properties, including their seasonal and ephemeral nature. Second, where they are not heavily disturbed, their association with the azonal thicket on ferricrete makes them an extremely rare habitat type. They provide a unique type of breeding ground for frogs and other animals that use seasonal water to breed.

The streams and rivers are valuable headwaters for a large surrounding region and are important breeding grounds for frogs. The streams that lead into the Torotorofotsy Wetlands are especially important for their role in maintaining and regulating the water levels and water quality of the marsh system.

The Torotorofotsy Wetlands are a highly sensitive and valuable ecosystem in the region and in Madagascar. It is valuable for its ecological function and biodiversity. The wetlands buffer the impact of heavy water runoff from the

Analamay plateau to downstream areas, and also stores water during periods of drought. Additionally, the wetlands function (as do most marshes) as a natural filter for sedimentation and as a reservoir to attenuate high runoff flows, thus reducing downstream erosion and sedimentation.

The ecology and biology (habitat diversity, habitat continuity, animal breeding) of the Torotorofotsy Wetlands is sensitive to water level and water quality fluctuations. The marsh contains valuable communities of mid-altitude marsh fauna. For example, the endangered slender-billed flufftail (*Sarothrura watersi*) which occurs there may require specific marsh vegetation. The distribution of this marsh vegetation, in turn, would be influenced by a combination of factors including water levels, nutrients, and the presence of competitors and predators. The marsh also provides habitat to a mixed taxonomic community of resident and transient marsh birds, fish, invertebrates, and small mammals.

4.2.4 Impact Assessment

4.2.4.1 Issue Scoping

The baseline summary described the key faunal species and faunal habitat found within the mine LSA, particularly for species of concern (IUCN 2004; UNEP-WCMC 2005) and priority species (local and regional endemics). The purpose of the impact assessment is to assess specific effects on the key species and habitats found within the LSA, identify strategies to reduce potential project-related effects and discuss the potential to return the area to pre-disturbed faunal habitat conditions. Various issues and concerns related to potential project impacts on fauna were raised during consultation, especially with environmental non-governmental organizations (Volume A, Section 6). Main issues connected to faunal species include:

- potential impacts (including extirpation or extinction) of locally endemic species associated with removal of azonal and transitional forest habitats;
- potential impacts to populations of rare and endangered species from mine construction and operation;
- direct and indirect effects on faunal habitats from construction and operations, especially in the Torotorofotsy Wetlands, as a result of changes in hydrology and hydrogeology;
- habitat fragmentation and potential impacts on movements of faunal species; and
- potential effects on faunal health due to changes in water and air quality.

These issues can be summarized by the following key questions:

- | | |
|-------------------------|---|
| Key Question W-1 | What Effect Will the Project Have on Faunal Abundance and Distribution Including the Persistence of Locally Endemic Species? |
| Key Question W-2 | What Effect Will the Project Have on the Movement of Faunal Species? |
| Key Question W-3 | What Effect Will the Project Have on Faunal Health? |

The Ambatovy Project footprint in the mine LSA consists of the mine site, including associated roads and infrastructure, and the water intake station and pipeline from the Mangoro River. The mine site, including a 50 m buffer on all sides for possible road routes and construction areas, is 17.3 km² in total area. Open areas of less than 1 ha within the project footprint have been assumed to be part of the footprint due to the edge effects on such small areas. The maximum disturbance area will not be reached until year 20 of the mine plan.

The 25 m wide corridor from the water intake station at the Mangoro River to Highway Route Nationale (RN) 44 will be 15 km long. This right of way includes:

- a dirt access road; and
- a buried water pipeline 600 mm in diameter.

At RN44, the corridor for the Mangoro water pipeline described above joins alongside the new mine access road right-of-way. The future route will follow the route of an existing dirt road, but the road must be widened and topped with gravel or crushed rock. The total corridor width (road and buried water pipeline) will be 40 m, and is 7.9 km in length from the highway to the mine. Therefore, the total length of the intake pipeline is about 23 km from the Mangoro River to the point at which it enters the mine footprint.

Impacts to fauna could occur during construction and operations as shown in the linkage diagram (Volume H, Appendix 9). For each effect associated with the Ambatovy Project, an analysis of potential impact pathways is provided for each issue, followed by a mitigation section, impact analysis, residual impact classification and monitoring. Where issues were related (e.g., edge effects), they were analyzed and discussed together to avoid repetition.

4.2.4.2 Key Question W-1 What Effect Will the Project Have on Faunal Abundance and Distribution Including the Persistence of Locally Endemic Species?

Habitat loss can result from activities during the construction and operation phases. Habitat loss can result from the following:

- site clearing;
- change in water flows;
- sensory disturbance;
- air emissions, including dust;
- fragmentation; and
- barriers to movement.

Direct habitat loss results from the physical removal of habitat through site clearing during the construction and operation phase of the Ambatovy Project. Direct habitat loss may also result through habitat fragmentation, where habitat quality is reduced to the point that it is no longer used by fauna or the habitat provides inadequate food resources for successful reproduction or decreased predator protection resulting in increased mortality. Wetlands drainage or water drawdown is another form of direct habitat loss.

Indirect habitat loss is when the habitat is still physically available but fauna choose not to, or may not be able to, use it as a result of physical barriers and sensory disturbance. Direct habitat loss and initial fragmentation are closely associated with the construction phase while barriers to movement, sensory disturbance and habitat loss from air emissions are more closely associated with the operational phase. However, both phases of the Ambatovy Project may result in direct and indirect habitat loss. Habitat fragmentation and barriers to movement are addressed under Key Question W-2.

Direct Habitat Loss

Site Clearing

Direct habitat loss is the most visible effect and occurs when land is cleared for other uses. Because some facilities (e.g., main roads) will be permanent for the life of the Ambatovy Project, habitat loss is a medium or long-term event for these features. Habitat loss may be temporary for other facilities (e.g., buried water intake pipelines).

Change in Water Flows

Wetlands drainage and groundwater or surface water drawdown can directly and indirectly remove or alter habitat for amphibians, waterbirds and other species that occur in wetlands (Coughanowr 1998). During construction and operations, headwaters will be mined or disturbed and water will be collected in the mine areas and held in containment ponds. Flow to the surrounding area, including the Torotorofotsy Wetlands, will be controlled.

Assessment Methods

Site Clearing

Changes in areal extent of each habitat type were assessed from baseline to impact case based on the mapped vegetation classification for the mine LSA. Impacts were assessed for total footprint although mining and reclamation will occur progressively over the life of the project. Thus, the impact analysis is conservative. Reclamation will restore habitat but was not assessed quantitatively.

Change in Hydrology

Changes in water flows from baseline to impact were assessed for the wet and dry seasons for the six watersheds in the mine area. Methods are described in detail in the Hydrology Section (Volume B, Section 3.8). Habitats, and associated species, occurring in each affected area were identified and potential impacts were discussed qualitatively.

Assessment Criteria

The assessment criteria used for fauna are presented in Table 4.2-1. Where quantitative values are not possible, results from the literature, local specialists and professional judgment were used to determine impacts.

Table 4.2-1 Impact Description Criteria for Fauna

| Direction ^(a) | Magnitude ^(b) | Geographic Extent ^(c) | Duration ^(d) | Reversibility ^(e) | Frequency ^(f) |
|--|---|---|---|-----------------------------------|---|
| 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 ^(g) 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 |

^(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 3-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.

^(g) RSA = regional study area.

Mitigation

Mitigations that will reduce the effects of habitat loss and alteration from site clearing and changes in hydrology in the mine LSA to wildlife include:

Design Elements

- Modification of footprint to reduce impacts including designation of on-site conservation areas.
- Mine plan to incorporate viable buffer zone, including azonal and transitional habitat (which will be specifically protected), to maintain connectivity between large habitat areas and permit recolonization of reclaimed sites.
- Mitigate effects on the Torotorofotsy Wetlands, through site design and water management plan (see hydrology and water quality sections: Volume B, Sections 3.8 and 3.9).

Mitigation Techniques

- Areas will be progressively mined and reclaimed during operations.
- Translocation of some key local endemic wildlife species to azonal or other similar habitats either on-site (within the mine LSA) or other identified off-site areas (outside the LSA). Species will be selected based on our ability to capture and move individuals that otherwise

would not move ahead of construction and availability of habitats to move individuals into. Subject to meeting these criteria, the first priority for release areas would be the two azonal protection areas within the mine lease.

Rehabilitation or Repair Approaches

- Decommissioning and reclamation of the site post-closure, including revegetation with native species. End land use will be determined based on regional planning goals.

Compensation

- On-site azonal and transitional habitat conservation.
- Additional off-site compensatory azonal habitat conservation (see Volume B, Section 4.1).

Impact Analysis

The maximum area of new disturbance for Ambatovy Project in the mine LSA will be 1,801 ha (Table 4.2-2). The mine site and associated infrastructure footprint will be 1,733 ha. The disturbance due to the Mangoro water intake pipeline and main access road from RN44 will be 67 ha. As a conservative estimate of impacts on faunal habitat, it was assumed that construction of all elements would occur at the same time.

Table 4.2-2 Change (%) in Habitat Area as a Result of Site Clearing from the Mine Site in the Local Study Area

| Habitat Type | Baseline Case (ha) | Impact Case (ha) | Change (ha) | Percent Change (%) |
|----------------------------|--------------------|------------------|---------------|--------------------|
| azonal | 1,380 | 396 | -984 | -71.3 |
| transitional | 1,489 | 1,151 | -338 | -22.7 |
| zonal | 12,527 | 12,156 | -371 | -3.0 |
| ephemeral ponds | 5 | 1 | -4 | -87.8 |
| marsh | 1,114 | 1,101 | -13 | -1.2 |
| marsh edge | 231 | 231 | 0 | 0 |
| river/water | 13 | 13 | 0 | 0 |
| other ^(a) | 6,134 | 6,043 | -91 | -1.5 |
| total^(b) | 22,892 | 21,092 | -1,801 | -7.6 |
| streams and rivers (km) | 160 | 122 | -38 | -23.7 |

^(a) Includes pasture, rice paddies, eucalyptus woodlots, slash and burn areas, and villages.

^(b) May not sum exactly due to rounding.

Habitat loss as a result of the mine site and infrastructure will be greatest in the azonal, transitional and ephemeral pond habitats with proportional losses of 71.3%, 22.7% and 87.8%, respectively. Approximately 40% (585 ha) of the azonal habitat and 50% (713 ha) of the transitional forest has been previously impacted by natural and human disturbance (see Appendix B, Section 4.1). As the ferricrete soil characteristics of azonal, transitional and ephemeral pond habitats cannot be reclaimed, losses will be permanent. Site clearing will impact 13 ha of marsh habitat, specifically in areas that have been modified by the production of rice. Over 90% of marsh habitat in the mine LSA is in this category (see Appendix B, Section 4.1). Total length of streams will decrease by 23.7% from 160 km to 122 km. Marsh edge and open water habitats are not predicted to be affected by the mine facilities or infrastructure. Slurry pipeline impacts within the mine LSA, including the section around the marsh, are evaluated in the Slurry Pipeline EA (Volume C, Section 4.2).

Species most likely to be affected include species locally endemic to the mine LSA, particularly if they occur within the mine footprint, and species only observed in the habitats that will be permanently lost. Three species were classified as local endemics; an ant, a frog and a snake. *Pilotrochus besmerus* is an ant species that was observed only in an area of clay soils in the transitional forest of the Ambatovy area. This site is within the on-site conservation area and as a result will not be disturbed by mine site clearing.

Two newly discovered species considered local endemics, *Boophis* nov. sp. (a frog) and *Liophidium* nov. sp. 1 (a snake), were also recorded during field surveys, although taxonomy has not yet been confirmed. Both species were only observed in 1997 in the azonal forest of Analamay on the edge of the mine footprint. *Liophidium* nov. sp. 1 was also observed in the zonal forest between Ambatovy and Torotorofotsy. As these species were not observed again during the 2004 surveys, they may not now be present in the study area. Additional surveys are warranted at the sites they were observed, within other areas of the mine LSA and other off-site areas to determine if these species are more widely distributed.

Ninety-nine species were only observed in azonal and transitional forests and are therefore at increased risk from site clearing (Table 4.2-3). A list of these habitat specialists is provided in Volume J, Appendix 2.2.

Table 4.2-3 Species Observed in a Single Habitat

| Species Group | Habitat | | | |
|----------------------------|-----------|--------------|-----------|----------|
| | Azonal | Transitional | Zonal | Marsh |
| herptiles | 16 | 8 | 4 | 6 |
| lemurs | 0 | 0 | 0 | 0 |
| small mammals | 3 | 2 | 4 | 0 |
| bats | 0 | 0 | 0 | 1 |
| ants | 7 | 9 | 7 | 0 |
| lepidopterans | 44 | 10 | 11 | 2 |
| total^(a) | 69 | 30 | 26 | 9 |

^(a) May not sum exactly due to rounding.

The mine site will be progressively reclaimed during operations. At closure, all buildings and facilities will be decommissioned and removed. Reclamation goals will be based on regional planning, including input from stakeholders and government. The biological goal of reclamation will be to develop a self-sufficient vegetative community that provides protection against erosion and multiple end uses, including faunal habitat. The azonal, transitional and ephemeral ponds habitats cannot be restored so these losses are permanent. Other forested habitats will replace these key habitats. Recent habitat evaluations at a potential off-site azonal conservation area, show many similarities to the project area, including the presence of seasonal ponds. Conservation of this off-site area will help compensate for residual faunal impacts on-site.

Change in Hydrology

Through design, the mine water management will result in seasonal downstream flows similar to those under baseline conditions. However, increases between 0% and 24% in downstream flows may occur during the wet season (for details refer to Volume B, Section 3.8).

Increased flows in the wet season could cause a change in vegetation communities, if elevated water flow causes increased moisture levels in soil or water levels in standing water. Vegetation communities most likely to be affected occur along the edges of standing water, such as the Torotorofotsy Wetlands. As these rare edge habitats have been identified as a key habitat for bats (other species groups were not sampled in this area), alteration in the distribution and extent of these vegetation communities could have an impact on fauna distribution and abundance in this habitat and the LSA.

Residual Impact Classification

Residual impacts and environmental consequences of direct habitat loss as a result of construction and operation of the Ambatovy Project are presented in Table 4.2-4. High environmental consequences were predicted for azonal, transitional and ephemeral pond habitats as a result of site clearing. These consequences were anticipated because >20% of these habitats within the LSA will be lost, and the effects are irreversible.

After mitigation, moderate environmental consequences as a result of site clearing are forecast for locally endemic faunal populations and those species only observed in azonal and transitional habitats in the LSA (Volume J, Appendix 2.2). At a regional level, the project is committed to supporting compensatory conservation of offsite azonal habitat. This commitment, including consideration of ongoing forest loss in Madagascar, is discussed more in the Cumulative Effects section (Volume G, Section 3.2), but is predicted to result in an overall positive impact in the long-term, if the mitigation is successful.

Table 4.2-4 Residual Impact Classification for Impacts Related to Direct Habitat Loss

| Component | Direction | Magnitude | Geographic Extent | Duration | Reversibility | Frequency | Environmental Consequence |
|--|-----------|-----------------|-------------------|-----------|---------------|-----------|---------------------------|
| Issue: Site Clearing | | | | | | | |
| azonal | negative | high | local | long-term | irreversible | low | high |
| transitional | negative | high | local | long-term | irreversible | low | high |
| zonal | negative | low | local | long-term | reversible | low | low |
| marsh | neutral | negligible | n/a | n/a | n/a | n/a | n/a |
| marsh edge | neutral | negligible | n/a | n/a | n/a | n/a | n/a |
| ephemeral ponds | negative | high | local | long-term | irreversible | low | high |
| streams | negative | high | local | long-term | reversible | low | high |
| local endemic species | negative | moderate | local | long-term | reversible | low | moderate |
| species only in azonal, transitional and ephemeral pond habitats | negative | moderate | local | long-term | reversible | low | moderate |
| other species | negative | low | local | long-term | reversible | low | low |
| Issue: Change in Water Flows | | | | | | | |
| habitats | negative | low to moderate | local | long-term | reversible | moderate | low to moderate |

Conversely, low environmental consequences associated with site clearing are predicted for zonal habitats. These consequences were primarily driven by low

magnitude ratings (<10% reduction in areal extent of zonal habitat). The residual impacts to species, including rare species that use other habitats are also predicted to be low.

The vegetation communities within the watershed basins in the mine LSA are predicted to be negatively impacted during mine operations due to increases of average flows during the wet season. This may increase existing flows by up to 24%, but because this change occurs only in the wet season, the magnitude and nature of the changes to vegetation communities is predicted to be low (Volume B, Section 4.1). Effects on fauna in the streams will be low to moderate.

Prediction Confidence

Prediction confidence for impacts to habitats as a result of site clearing is high. Prediction confidence for impacts to habitats as a result of changes in water flow is medium, as water flows are understood and can be controlled through the mine water management system, but the ecology of stream systems is less well understood.

Uncertainties in the impact predictions for fauna as a result of direct habitat loss include:

- Species accumulation curves by habitat type indicate that additional species are predicted to occur in all habitats (see Volume J, Appendix 2.1). Therefore, it is possible that the number of species determined to occur in only one habitat was overestimated or that local endemics are more widely distributed.
- The ecology of watersheds, including vegetation response to changes in water levels and faunal species habitat requirements, seasonal use and movements in the mine LSA are not well understood.

Monitoring

A fauna monitoring plan is proposed to document the effects of construction, operation and reclamation of the mine on key faunal species groups within the conservation zones. The program will periodically determine the distribution and abundance of the key species, including transplanted species, within the conservation areas. A program will also be established to monitor habitat reclamation upon reclamation and closure.

Species groups that may be monitored include amphibians and reptiles, birds, lemurs, small mammals and *Ptilopus* colonies. Monitoring methods will be dependant on the species groups. A fauna observation log will be implemented and workers will be encouraged to report faunal observations (i.e., sightings,

calls, nests) for selected species. These recorded observations will help assess changes in faunal abundance and distribution.

Indirect Habitat Loss

Sensory Disturbance (noise and light)

Sensory disturbance may result from both construction and operations and may lead to displacement effects and changes in fauna abundance (Forman 1995). Indirect habitat loss may occur as a result of sensory disturbances from human activities (e.g., human movement and noise, vehicles, noise and lights from vehicles and facilities). While a habitat may contain suitable cover and forage, the habitat may not be used by fauna due to sensory disturbance (e.g., noise, lights). The end result is habitat alienation or loss of habitat effectiveness.

Sensory disturbance also can result in increased levels of stress and energy expenditure and disruption of feeding and/or mating behaviour, and can lead to increased mortality and/or lower reproductive rates. Such impacts are not as visible as habitat loss but can be just as harmful (Cuarón 2000, Blom et al. 2004, Dahlgren and Korschgen 1992). While short-term evidence of disturbance is often apparent, long-term effects are difficult to observe. Several reviews of the topic in different environments and with select species have been done (Shank 1979; Prism 1982; Bromley 1985; Komex 1995).

Sensory disturbances can vary in intensity and duration, from passive and benign activities to direct and persistent harassment. In many cases fauna may habituate to noise, but this varies among individuals and species and often depends on the predictability of the disturbance (Bowles 1995). Other activities may increase the effects of noise. For example, faunal species that are hunted are more likely to flee because of noise (e.g., lemurs, Schmid 2000). While single-disturbance effects may be insignificant, effects can be cumulative (e.g., lemurs, Smith et al. 1997).

In general, sensory disturbances tend to be most detrimental at critical times of the year, such as during breeding, particularly for those species that rely on vocalization as part of the breeding strategy, and when adults are raising their young (e.g., anurans, Barass 1985).

Dust Effects

Increased wind speeds at disturbance edges increase the transfer of dust into neighboring undisturbed habitat (Saunders et al. 1991). Dust can affect photosynthesis, respiration, transpiration and facilitate impacts from pollutants (Farmer 1993). Faunal species most likely to be affected are those dependent on

rare sensitive plant species and herbivores and amphibians occupying the affected areas. Herbivores may be impacted by dust on forage plants if it affects nutrition or results in increased tooth wear (Williams and Kay 2001). Dust deposition directly on individuals or introduced into aquatic systems (e.g., increase in turbidity) may have negative effects on amphibians (Marsh and Beckman 2004).

Dust is likely only an issue in the dry season, unless dust has negative chemical/physical properties (leaching, water turbidity) that affect plant growth throughout the year.

Introduction of Non-Native and Invasive Species

Invasion by non-native and invasive species into pristine habitats can have drastic consequences on the natural balance of an ecosystem (Forman 1995). When non-native or invasive plants or animals (e.g., *Rattus rattus*) are introduced or invade from an adjacent area, they may compete with native species resulting in a reduction in a decline in small mammals (Goodman et al. 2003, Stephenson 1993). In most instances, communities with fewer species are easier to invade. Thus, early successional habitats with few species created by disturbance of ecosystems naturally (e.g., cyclones, Fisher 2003) or anthropogenically (e.g., forest harvesting, mine clearing) provide habitat that is generally much easier to invade than 'old' communities (Pimm 1994). Twenty-five ant species have likely been introduced to Madagascar (Fisher 2003). The presence of invasive ant species in disturbed and fragmented habitat is associated with the reduction in native ant populations (Fisher et al. 1998 cited in Fisher 2003).

With an increase in human activity due to the construction and operation of the Ambatovy Project, there is an increased likelihood of introduction of non-native and invasive species to previously undisturbed areas. The occurrence and habitats of non-native and invasive species at baseline are presented in the Fauna Baseline (Volume J, Appendix 2.1). There is the potential for these species to invade disturbed areas of the Ambatovy Project.

Increased access and increased edge as a result of development provides a mechanism for both introduction (i.e., carried in by humans) and invasion (i.e., encroachment from adjacent areas) of non-native and invasive plant and animal species. Therefore, this factor falls under both indirect habitat changes and change in access.

Changes in Microclimate

Forest edge differs from forest interior in both microclimatic and biotic aspects (Forman 1995). A transition in microclimatic variables such as light intensity,

temperature, wind and humidity occurs from an edge to a forest interior (Davies-Colley and van Elswijk 2000). Both vegetation and faunal species respond to these microclimatic differences; the changes are advantageous for some species and a disadvantage for others (With 2002). Clearing of the mine site will increase the amount of edge habitat between forested and non-forested land.

Assessment Methods

Sensory Disturbance

Noise

Noise levels during construction and operation were modeled using conservative assumptions and compared with baseline levels to determine potential impacts (Volume B, Section 3.5). Noise was considered an impact to wildlife when it exceeded the 45 dBA nighttime or 55 dBA daytime noise level criteria as defined by World Bank for people (The World Bank Group 1999). The areal extent of each habitat type within the two modeled noise bands was calculated to determine impacts (>45 dBA and >55 dBA).

Residual impacts are calculated for levels above 45 dBA as noise levels below this criterion are considered within acceptable levels. A qualitative assessment of impacts to species using these habitats is discussed. The area of each habitat impacted by these edge effects is additive to direct habitat losses and should be considered with losses due to other indirect effects.

Light

Although light effects are well documented (Longcore and Rich 2004), there is limited quantitative information in the literature. In Madagascar, light traps were used to catch hundreds of mayflies (*Probosciodoplocia spp.*) in a few minutes during surveys (Elouard et al. 2003) and lighting associated with a mine would likely do the same, possibly resulting in increased predation by bats and other nocturnal insect feeders (e.g., Frank 1988). Effects of light on fauna were assessed qualitatively.

Dust Effects

Spatial modelling of dust was completed based on project activities over the life of the project (Volume B, Section 3.4). Zones of influence were mapped and overlain on the vegetation map to calculate the areal extent of each habitat type affected. Potential impacts to vegetation are discussed and assessed in Volume B, Section 4.1. Based on the residual impacts predicted for vegetation, a qualitative assessment of the potential effects to faunal species is discussed.

Introduction of Non-Native and Invasive Species and Microclimatic Changes

Although known to occur in Madagascar (see examples in Goodman and Benstead 2003), rates of invasion of non-native and invasive species and influence of microclimate changes on fauna and habitats are not known for this system. As a result, individual edge effects cannot be directly quantified.

To assess impacts due to edge effects, it was assumed that these effects all occur within a particular distance from all human-caused edges. All mine facilities and infrastructure were buffered by 100 m and the areal extent of each habitat type within the buffer zone was calculated to determine impacts. A buffer width of 100 m was used based on the median impact distance reported for a variety of ecosystems (e.g., invasive species: 100's to 1,000's m [Brocke et al. 1990 cited in Forman 1995]; microclimate effects: up to 50 m [Turton and Siegenthaler 2001]). A qualitative assessment of impacts to species using these affected habitats is discussed. The area of each habitat impacted by these edge effects is additive to direct habitat losses and should be considered with losses due to other indirect effects.

Assessment Criteria

The assessment criteria are the same as for direct habitat loss (see Table 4.2-1).

Mitigation

Mitigations that will reduce indirect habitat loss and alteration due to sensory disturbance, introduction of non-native and invasive species, dust effects and changes in microclimate in the mine LSA include:

Design Elements

- Mufflers on vehicles to reduce noise.
- Slurry pump station enclosed in a building.
- Lights will be shielded and/or directed away from adjacent habitat.

Mitigation Techniques

- Control of exotic and invasive plant species.
- Trapping and removal of non-native rodents around the camp and other buildings.
- Control dust through routine road watering.

Reclamation and Closure

- Cessation of operations and revegetation with native species will remove sensory disturbance and reduce edge effects.

Impact Analysis

Sensory Disturbance

Existing noise levels range from 20 to 42 dBA, depending on location and time of day (Volume B, Section 3.5, Table 3.5-1). Impacts to habitats beyond the mine footprint from project-generated noise are provided in Table 4.2-5. Primary noise sources include the engine generator area, scrubber area, haul truck traffic, process water pumps and the mine face pit (Volume B, Section 3.5). Overall, azonal, transitional, zonal and ephemeral pond habitats will, proportionately, be impacted the most by noise generated by mine activities. Azonal and transitional habitats will be impacted the most (7.6 and 14.2% respectively) by noise levels above 45 dBA given their proximity to the mine area. Marsh and marsh edge habitats will only be affected by noise levels above baseline but not exceeding 45 dBA.

Species most likely to be affected by noise include species that use vocalization for breeding (e.g., amphibians, birds, lemurs) and wary species in areas where noise exceeds baseline levels, including in the on-site conservation areas. If noise levels interfere with the ability of individuals to find mates, there could be potential population effects locally over time. For rare species, these effects could be regional or beyond regional.

Species most likely to be affected by light include species that are drawn to light (e.g., moths and insectivorous species such as bats) and those species that are light sensitive (e.g., Elouard et al. 2003). None of the moth species recorded during the surveys was identified as rare. Light mitigation will help reduce impacts and observing the species attracted to the lights will help determine extent of the impacts and whether additional mitigation is required.

Table 4.2-5 Impact (ha) on Habitats as a Result of Project-Generated Noise Within the Local Study Area

| Noise Range | Habitat Type | Baseline (ha) | Area Impacted (ha) | % Indirect Habitat Loss |
|-----------------------------|----------------------|---------------|--------------------|-------------------------|
| >55 dBA ^(a) | azonal | 1,380 | -32 | -2.3 |
| | transitional | 1,489 | -61 | -4.1 |
| | zonal | 12,527 | -112 | -0.9 |
| | ephemeral ponds | 5 | 0 | 0 |
| | marsh | 1,114 | 0 | 0 |
| | marsh edge | 23 | 0 | 0 |
| | river/water | 13 | 0 | 0 |
| | other ^(b) | 6,134 | -1 | -<0.1 |
| 45 to 55 dBA ^(c) | azonal | 1,380 | -73 | -5.3 |
| | transitional | 1,489 | -150 | -10.1 |
| | zonal | 12,527 | -350 | -2.8 |
| | ephemeral ponds | 5 | -<1 | -1.6 |
| | marsh | 1,114 | 0 | 0 |
| | marsh edge | 231 | 0 | 0 |
| | river/water | 13 | 0 | 0 |
| | other ^(b) | 6,134 | -1 | -<0.1 |
| total | azonal | 1,380 | -105 | -7.6 |
| | transitional | 1,489 | -211 | -14.2 |
| | zonal | 12,527 | -462 | -3.7 |
| | ephemeral ponds | 5 | -<1 | -1.6 |
| | marsh | 1,114 | 0 | 0 |
| | marsh edge | 231 | 0 | 0 |
| | river/water | 13 | 0 | 0 |
| | other ^(b) | 6,134 | -2 | -<0.1 |

^(a) Noise levels above daytime World Bank maximum levels for people (The World Bank Group 1999).

^(b) Includes pasture, rice paddies, eucalyptus woodlots, slash and burn areas, and villages.

^(c) Range between nighttime and daytime World Bank maximum levels for people.

Dust Effects

The estimated aerial extent of dust exceeding a concentration level of 20 micrograms/m³ is 1,118 ha (5% of the mine LSA) after removing all direct effects as a result of site clearing. The 20 micrograms/m³ guideline was used as a conservative measure and was based on vegetation effects reported in out-of-country studies (see Volume B, Section 4.1 for full discussion).

Zonal forests will be most affected by dust based on areal extent (853 ha; 4% of the mine LSA). However, a greater proportion of the azonal (6%; 77 ha) and

transitional habitats (12%; 186 ha) will be impacted by dust. As discussed in Volume B, Section 4.1, plants most sensitive to the effects of dust may be vegetation on the ground and in particular lichens, mosses and other life forms that derive some of their moisture and nutrient requirements from the air such as epiphytic orchids. These plants include some rare species thought to be specific to azonal and transitional habitats.

Most of the dust is predicted to be dispersed outside of the proposed azonal conservation areas. At Analamay, no dust is predicted to occur within this conservation zone. Within the conservation area at Ambatovy, dust is predicted to be dispersed over an area of 10 ha (10% of Ambatovy conservation area).

Introduction of Non-Native and Invasive Species and Microclimatic Changes

The largest potential impacts as a result of edge effects due to mine construction and operation will be to azonal, transitional and ephemeral pond habitats with proportional losses of 11.1%, 11.6% and 4.3%, respectively (Table 4.2-6). Edge effects will influence 255 ha of zonal habitats (2.0%) and 455 ha of “other” habitats. These impacts are in addition to the direct losses due to site clearing. The marsh and marsh edge habitats are not predicted to be impacted by non-native and invasive species or microclimate changes due to edge creation.

Table 4.2-6 Habitats (ha) Within a 100 m Edge Effects Zone of the Mine Site Local Study Area

| Habitat Type | Baseline (ha) | Area Impacted (ha) | % Indirect Habitat Loss |
|----------------------|---------------|--------------------|-------------------------|
| azonal | 1,380 | -153 | -11.1 |
| transitional | 1,489 | -172 | -11.6 |
| zonal | 12,527 | -255 | -2.0 |
| ephemeral ponds | 5 | -<1 | -4.3 |
| marsh | 1,114 | 0 | 0.0 |
| marsh edge | 231 | 0 | 0.0 |
| river/water | 13 | 0 | 0 |
| other ^(a) | 6,134 | -455 | -7.4 |
| total | 22,892 | -1,034.8 | -4.5 |

^(a) Includes pasture, rice paddies, eucalyptus woodlots, slash and burn areas, and villages.

Residual Impact Classification

Residual impacts as a result of indirect effects are provided in Table 4.2-7.

Table 4.2-7 Residual Impact Classification for Fauna due to Indirect Habitat Loss

| Taxon | Direction | Magnitude | Geographic Extent | Duration | Reversibility | Frequency | Environmental Consequence |
|--|---------------------|------------|-------------------|-------------|---------------|-----------|---------------------------|
| Issue: Sensory Disturbance – Noise | | | | | | | |
| azonal | negative | low | local | medium-term | reversible | high | low |
| transitional | negative | moderate | local | medium-term | reversible | high | low |
| zonal | negative | low | local | medium-term | reversible | high | low |
| ephemeral ponds | negative | low | local | medium-term | reversible | high | low |
| marsh | negative | low | local | medium-term | reversible | high | low |
| marsh edge | negative | low | local | medium-term | reversible | high | low |
| species using vocalization for breeding | negative | low | local | medium-term | reversible | low | low |
| wary species | negative | low | local | medium-term | reversible | low | low |
| other species | neutral to negative | negligible | local | medium-term | reversible | low | negligible |
| Issue: Sensory Disturbance – Lights | | | | | | | |
| species attracted to lights | negative | low | local | medium-term | reversible | moderate | low |
| species that avoid light | negative | low | local | medium-term | reversible | moderate | low |
| other species | neutral | n/a | n/a | n/a | reversible | n/a | n/a |
| Issue: Dustfall | | | | | | | |
| species dependant on rare sensitive plant species | negative | low | local | medium-term | reversible | moderate | low |
| herbivores | negative | low | local | medium-term | reversible | moderate | low |
| amphibians | negative | low | local | medium-term | reversible | moderate | low |
| Issue: Invasive Species and Changes in Microclimate | | | | | | | |
| azonal | negative | moderate | local | long-term | reversible | high | moderate |
| transitional | negative | moderate | local | long-term | reversible | high | moderate |
| zonal | negative | low | local | long-term | reversible | high | low |
| ephemeral ponds | negative | low | local | long-term | reversible | high | low |
| marsh | neutral | n/a | n/a | n/a | n/a | n/a | n/a |
| marsh edge | neutral | n/a | n/a | n/a | n/a | n/a | n/a |
| species in azonal and transitional habitats | negative | moderate | local | long-term | reversible | high | moderate |
| species in other habitats | negative | low | local | long-term | reversible | high | low |

n/a = Not applicable.

Sensory Disturbance

Noise

The environmental consequence of project-generated noise is negative and low for all habitats. The transitional forest is the only habitat that will experience a moderate magnitude of impact based on the areal extent of noise levels greater than 45 dBA. Noise levels above 45 dBA will affect <10% of the area of each of the other habitats. Effects will last the duration of mine operations and will be continuous. The environmental consequence is predicted to be low for species using vocalization for breeding and wary species primarily because noise effects are predicted to be low. Effects are predicted to be neutral to negligible for all other species. All project-related noise effects will be removed at closure.

Light

The environmental consequence of light is predicted to be low if mitigation is successful. None of the moth species recorded during the surveys was identified as rare so the impacts for this species group are also likely low.

Dust Effects

Faunal species that will be most affected may be those dependent on rare plant species sensitive to dust, and herbivores and amphibians within the zone of influence. However, as the on-site conservation areas will not be infiltrated by dust to any great extent, it is unlikely that populations of rare plants in these areas will be negatively affected. Thus, impacts to dependent fauna are predicted to be low. Impacts to herbivore and amphibian populations are also predicted to be low, as the areal extent of fugitive dust is low to moderate and, with the seasonal rains, will not occur continuously.

Invasive Species and Changes in Microclimate

The environmental consequence of edge effects due to invasive species encroachment and changes in microclimate is negative and moderate for azonal and transitional habitats because the magnitude of the habitat loss is moderate; the duration is long-term as it will last until the site is reclaimed and the effects will be continuous. All other habitats in the mine LSA are predicted to have a low environmental consequence because the magnitude of the areal extent of the impact is low. The environmental consequence of invasive species and changes in microclimate for fauna is predicted to be moderate for animals occupying azonal and transitional habitats in the mine LSA and low for animals occupying other habitats.

Prediction Confidence

Prediction confidence for areal extent of impacts to habitats as a result of noise and edge effects is moderate to high as these impacts were spatially modelled. It

is difficult to predict the impacts to fauna from dust and light effects, so prediction confidence is low. Although the linkages from these indirect effects to fauna impacts have been well documented, it is difficult to translate these impacts to changes in populations, because the demographics of fauna populations as well as the effects on species are unknown. Therefore, the prediction confidence for the actual impacts of indirect effects on different fauna species is low as a result.

Monitoring

Monitoring indirect impacts will be as described for direct effects, although the information will be coupled with periodic noise and dust level monitoring. In addition, periodic observations will be made on species being attracted to lights.

Direct Mortality

Direct Mortality From Site Clearing

Clearing of vegetation and removal of soil may kill animals that are less mobile or that have small home ranges. Animals with limited mobility and juvenile animals, including those in nests, are particularly sensitive to mortality through site clearing. Although adult birds can fly away from disturbance, nestlings are vulnerable during site clearing. Lizards with limited mobility and amphibians, as well as small mammals, may also be susceptible to this mortality source.

Nuisance Fauna

Nuisance fauna are undesirable species and can include native and non-native species. Non-native species are addressed in the previous section on indirect effects. The species of concern here are native species that are attracted to the mine facilities (e.g., carnivores, rodents) and become problematic or a hazard and need to be removed. If individuals must be destroyed, this can affect local populations of the species if the species has low fecundity, or regional populations if the species has low fecundity and is rare.

Interaction of Fauna With Infrastructure

There are two main aspects of infrastructure that may affect fauna: structures and ponds. Impacts of other infrastructure such as roads have been considered concerning barriers to movement; changes in hunting/collecting; and increased vehicle-fauna collisions. The containment ponds could have the potential to trap animals, causing death, if the edges or bottoms are soft.

Vehicle-Fauna Collisions

Virtually all fauna species are subject to road mortality. This topic has been the subject of many literature reviews (e.g., Jalkotzy et al. 1997; Australian rainforest

- Rainforest CRC 2004) and has been an important concern in most developments. Road mortality may cause a decline in local populations, but the effects are site-specific, depending on the species and the circumstances (e.g., type of road, volume of traffic). Crossing structures have been used effectively for a range of species in a variety of habitats (underpasses/culverts: herpetofauna, small mammals, carnivores [Goosem et al. 2001, Taylor and Goldingay 2001]; rope bridges: small mammals (northern Australia, including tropical systems [e.g., Goosem and Marsh 1997, Weston 2003]).

Seasonal effects have been reported for herpetofauna. In a tropical environment, higher impacts were reported during the wet season when amphibians were more inclined to cross roads that were inhospitable in the dry season.

Road mortalities are difficult to quantify, and only a portion of the mortalities that occur are ever reported (Kelsall and Simpson 1987). Often, mortalities are dispersed along many kilometres of complex road networks, and carcasses of small mammals and birds killed on roads are often quickly scavenged. Frequencies of road mortalities are often related to specific locations, traffic volume and speed (e.g., amphibians and road traffic volume - Mazerolle 2004, specific locations – Izumi 2001). Thus, educating Ambatovy Project personnel and posting speed limits and fauna crossing signs may alleviate some of the potential problems.

Hunting/Collecting

New access (e.g., roads, trails) provides increased opportunities for humans to use a previously less accessible area. Increased access can result in increased mortality from human hunters and poachers (Brody and Pelton 1989; McLellan 1988). Several of the key species identified for the Ambatovy Project are hunted for food (e.g., large lemur species) or collected for export (*Mantella* frogs, *Phelsuma* geckos).

Assessment Methods

Areal extent of site clearing (ha) was determined as per direct habitat loss. A qualitative discussion of the impacts to fauna is discussed.

A qualitative assessment was done for nuisance fauna, interaction with infrastructure, vehicle-fauna collisions and hunting/collecting as these effects could not be quantified.

Assessment Criteria

The assessment criteria are the same as for direct habitat loss (see Table 4.2-1).

Mitigation

Design Elements

- fauna crossing structures: below-road culverts (herpetofauna, small mammals) and above-road rope bridges (lemurs, arboreal herpetofauna and small mammals);

Mitigation Techniques

- relocation of key fauna species before site clearing;
- a manned gate will be installed at the entrance to the mine;
- vehicles restricted to designated roads and work areas;
- signage and post speed limits;
- outdoor pets not permitted in the mine area;
- develop waste management plan;
- trapping and removal of non-native rodents around the camp and other buildings;
- worker training program;
- public education program, particularly in the on-site conservation areas; and
- on site, no hunting permitted.

Reclamation and Closure

- Infrastructure, including roads, decommissioned and reclaimed at closure.

Impact Analysis

Site Clearing

A maximum of 1,801 ha of new clearings and disturbances will result from the Ambatovy Project activities. Areas most impacted include azonal, transitional and ephemeral pond habitats (see Table 4.2-2), thus the species occupying these habitats are most at risk for mortality. For lemur species, the number of individuals that may potentially be killed or displaced due to site clearing was estimated based on density estimates calculated from baseline surveys (Volume J, Appendix 2.1) and are reported in Table 4.2-8. The results are based on a clearing area of 1,300 ha of primary forest. All of the zonal forest and 40 to 50% of the azonal and transitional forests in the 1,700 ha forest area to be cleared has been disturbed. As lemur densities are likely lower in the more highly disturbed areas, the estimate of mortality and displacement is conservative. The small nocturnal species will be the most impacted as these species stay in their tree holes during the day.

Table 4.2-8 Potential Impacts to Lemur Populations Due to Site Clearing

| Species | Population Implications ^(a) | Potential Impact | IUCN status |
|----------------------------|--|---------------------|-----------------------|
| <i>Avahi laniger</i> | 142 | death /displacement | near threatened |
| <i>Cheirogaleus major</i> | 254 | death /displacement | none |
| <i>Eulemur fulvus</i> | 89 | displacement | near threatened |
| <i>Eulemur rubriventer</i> | unknown ^(b) | displacement | vulnerable |
| <i>Haplemur griseus</i> | 77 | displacement | near threatened |
| <i>Indri indri</i> | 25 | displacement | endangered |
| <i>Lepilemur sp.</i> | unknown ^(b) | death /displacement | near threatened |
| <i>Microcebus rufus</i> | 2,066 | death /displacement | none |
| <i>Propithecus diadema</i> | 37 | displacement | critically endangered |

^(a) Values are based on a clearing area of 13 km² of primary forest. All of the zonal forest and 40 to 50% of the azonal and transitional forests in the 1,700 ha forest area to be cleared has been disturbed so the potential impact estimate is conservative.

^(b) Density estimates for *Lepilemur mustelinus* and *Eulemur rubriventer* were not calculated because there were insufficient number of observations of these species.

Residual Impact Classification

Residual impacts as a result of indirect effects are provided in Table 4.2-9.

Site Clearing

Direct mortality impacts due to site clearing will particularly affect slow-moving or immobile animals, including young, and locally endemic or rare species that are low in abundance. For all but wide-ranging species, the environmental consequence is low because the magnitude is moderate, the effects are local and the duration is medium-term as effects will last the life of the mine. The effects are reversible if remaining populations can compensate for losses and the frequency is low as site clearing occurs only once in a given area. Mitigation, including pre-construction translocation of some key species and establishment of on-site conservation areas, will reduce impacts.

Nuisance Fauna

With effective mitigation, impacts should be low.

Interaction with infrastructure

Fauna interactions with infrastructure are expected to occur though the impact of such hazards is difficult to predict, since such numbers are hard to obtain and are often incomplete when available (Berger 1995).

Table 4.2-9 Residual Impact Classification for Fauna due to Direct Mortality

| Taxon | Direction | Magnitude | Geographic Extent | Duration | Reversibility | Frequency | Environmental Consequence |
|--|-----------|------------|-------------------|-------------|---------------|-----------|---------------------------|
| Issue: Direct Mortality from Site Clearing | | | | | | | |
| rare species | negative | moderate | local | medium-term | reversible | low | low |
| slow-moving or sessile species | negative | moderate | local | medium-term | reversible | low | low |
| wide-ranging species | negative | moderate | regional | medium-term | reversible | medium | moderate |
| other species | negative | moderate | local | medium-term | reversible | low | low |
| Issue: Nuisance Fauna | | | | | | | |
| native nuisance species | negative | low | local | medium-term | reversible | medium | low |
| other species | neutral | n/a | n/a | n/a | n/a | n/a | n/a |
| Issue: Interaction of Fauna with Infrastructure | | | | | | | |
| mobile species | negative | negligible | local | medium-term | reversible | medium | negligible |
| Issue: Vehicle-Fauna Collisions | | | | | | | |
| rare terrestrial species | negative | low | local | medium-term | reversible | medium | low |
| slow-moving terrestrial species | negative | low | local | medium-term | reversible | medium | low |
| wide-ranging species | negative | low | regional | medium-term | reversible | medium | moderate |
| other species | negative | low | local | medium-term | reversible | medium | low |
| Issue: Hunting/Collecting | | | | | | | |
| rare species | negative | low | local | medium-term | reversible | medium | low |
| other hunted and collected species | negative | low | local | medium-term | reversible | medium | low |
| wide-ranging species | negative | low | regional | medium-term | reversible | medium | moderate |
| other species | neutral | n/a | n/a | n/a | n/a | n/a | n/a |

n/a = Not applicable.

Vehicle-Fauna Collisions

Vehicle-fauna collisions are expected to occur and be greatest in areas of highest or continuous traffic volume and in high value habitats. Traffic volumes are predicted to be highest along the haul roads. In addition, vehicle traffic will increase in the surrounding area, outside the LSA, due to the Ambatovy Project (Volume B, Section 5.5).

The magnitude of impacts will likely be greatest for slow-moving terrestrial species as they are most at risk, and rare species or species with low fecundity, as losses of individuals can potentially affect populations. The environmental consequence, however, will be greatest for wide-ranging species because effects may impact regional populations. For all affected species, the impact duration will be medium-term as effects will last the life of the mine. The effects are reversible if remaining populations can compensate for losses and the frequency is medium as losses will occur intermittently. Mitigation, including fauna crossing structures, worker education, speed limits and signage, will reduce the magnitude of these impacts (i.e., collision rates) and mitigation monitoring will determine if adjustments are required.

Hunting and Collecting

It is difficult to predict the magnitude of this impact with any certainty. With effective mitigation, particularly worker and public education, impacts should be low. Again, the environmental consequence may be greater for wide-ranging species if regional populations are affected.

Prediction Confidence

Prediction confidence for direct mortality is medium for the following reasons:

- While the relative effects can be well assessed, it is more difficult to determine the environmental consequence due to these effects because the demography of the population and the magnitude of these effects on populations are less well understood.
- The geographic extent of the effects on local endemics and rare species is understood for direct impacts but is uncertain in relation to indirect effects.

Monitoring

Monitoring will be conducted to help determine if mitigation is effective or if adjustments must be made. The proponent will carry out a fauna monitoring program that includes:

- A fauna log for incidental observations during construction and operation. Any species removed prior to and during clearing or operations (i.e., nuisance animals) will be recorded. Workers will be encouraged to report fauna observations (i.e., sightings, calls, sign) for key species.
- Driving behaviour will be monitored both for safety and fauna protection concerns. Any regularly used faunal trails that are observed crossing roadways will be identified for placement of signage.

- Crossing structures will be monitored to determine species and frequency of use. Adjustments to structures will be made as necessary based on results.
- Animal traps or snares observed during monitoring surveys in the surrounding areas will be documented and removed.

Conclusions

Mine construction will have a high impact on faunal habitats linked to the zonal and transitional forest, including the aquatic habitats. As noted for flora, this is owing to the direct association between these vegetation types and the ore bodies. On-site and off-site azonal habitat conservation areas will respectively mitigate and compensate for both direct and indirect impacts to these habitats. A set of mitigations will be used to minimize direct mortality to fauna during both construction and operations. Appropriate monitoring will be used to ensure all mitigation is effective, or, if it is found not to be, to improve the mitigation as needed.

4.2.4.3 Key Question W-2 What Effect Will the Project Have on the Movement of Faunal Species?

Potential Impact Pathways

Fragmentation

Habitat fragmentation is another direct effect that occurs as a result of site clearing. Fragmentation occurs when extensive, continuous tracts of habitat are dissected into smaller, more isolated patches (Meffe and Carroll 1994). For most faunal species, small, dispersed habitat patches are considered to be lower quality than larger, continuous tracts. Often the process of fragmentation results in unconnected habitat fragments with a high proportion of open perimeters. Thus, fragmentation increases the amount of edge in the habitat, decreases the amount of habitat interior and increases the distance between habitat patches.

Indirect effects as a result of edge creation can contribute to fragmentation impacts. Forest edge differs from forest interior in both microclimatic and biotic aspects (see Indirect Habitat Loss Section in Key Question W-1). Some fragmentation changes can be positive (e.g., butterfly abundance is higher in clearings if suitable habitat exists). However, fragmentation has a negative effect on species that require extensive tracts of habitat (e.g., interior forest and wary species).

Road construction is a major contributor to habitat fragmentation in forested habitats (Reed et al. 1996). Some other disturbances that result in fragmentation

include forest clearing for developments, forest clear-cutting and right-of-way construction (e.g., pipelines, utility corridors).

Barriers to Movement

Faunal movements can be affected through the creation of physical or psychological barriers to movement (e.g., roads, facilities). Barriers can indirectly result in habitat loss by preventing animals from accessing habitat. Large (e.g., Ambatovy Project infrastructure) and narrow disturbances, such as linear corridors (e.g., roads and electrical transmission lines), can affect faunal movement. Barriers to movement may be a result of activities associated with both construction and operation phases.

Blockage of faunal movement and dispersal corridors is an increasing concern among conservation biologists and the public. Fauna corridors facilitate the movement of animals between larger patches of habitat (Soule 1991). With increasing development pressure and fragmentation of faunal habitat, species are often confined to patches of habitat or “habitat islands”. If isolated populations are not able to interact, a decrease in genetic diversity could result, leading to an overall decrease in the adaptability of the regional population. These effects may not be immediately apparent. It is therefore important to maintain connectivity among habitat patches at the landscape level.

Other effects may result from the disruption of natural movement corridors. Fauna need to move between habitats on a daily and seasonal basis. Often this movement is in search of suitable feeding, nesting, denning or resting areas. Long-distance movements may be undertaken to find mates, secure or expand a home range, or to accommodate seasonal changes in food or weather. For some species (e.g., lemurs), long-distance movements are essential to maintaining genetic variability over large areas.

The objective in planning faunal corridors is to allow for sufficient movement between habitat islands such that a species can persist in the region. Corridors must provide for daily, seasonal, annual and/or dispersal movements. In the context of the Ambatovy Project, corridors can also expedite the recolonization of reclaimed habitats and provide connectivity to the residual conservation areas and the Mantadia-Zahamena Conservation corridor. There is little information on how to design corridors for different species. However, Beier and Loe (1992) state that corridors that act as dispersal routes for species must be able to fulfill five functions:

- permit wide-ranging animals to travel, migrate and mate;
- allow plants to propagate;

- allow for genetic interchange to occur;
- allow populations to move in response to natural disasters; and
- allow individuals to recolonize habitats from which populations have been locally extirpated.

The Ambatovy Project will progressively exclude most animals from using the development footprint for travel until reclamation. Other facilities, such as access roads and transmission lines, as well as sensory disturbance, could act as partial barriers for some species. However, it is important to note that the Ambatovy Project will be a staged development, in that not all proposed activities will occur at once.

Assessment Methods

Fragmentation

Fragmentation analyses were conducted as part of the Biodiversity assessment (Volume B, Section 4.4) and methods are summarized here. Four indices were generated to determine changes in landscape composition and structure and changes in landscape connectivity from baseline to impact. Number of patches, patch area and total edge were used to assess changes in landscape composition and structure. Mean nearest neighbour distance was used to assess changes in landscape connectivity.

Four fragmentation analyses were performed to describe the current composition and configuration (or partitioning) of natural and disturbed patches of habitat (landscape classes) within the mine areas:

- terrestrial and wetlands habitat types;
- forested versus non-forested areas;
- disturbed versus non-disturbed areas; and
- disturbance type.

It was assumed that most species prefer large tracts of uninterrupted habitat or a 'well-connected' landscape. This translates to fewer, larger patches and low nearest neighbour distances. Assessments were based on examining the changes in all indices between baseline and impact cases. In general, fragmentation was considered to be negative if changes in the indices resulted in more, smaller patches and increased nearest neighbour distances. A qualitative assessment of impacts to faunal movement as a result of habitat fragmentation is provided.

Barriers to Movement

To assess impacts due to barriers to faunal movement created by the Ambatovy Project, the length of human-caused edge was calculated. Total edge was taken from the fragmentation analyses (Volume B, Section 4.4).

Assessment Criteria

The assessment criteria are the same as for direct habitat loss (see Table 4.2-1).

Mitigation

Design Elements

- Mine plan to incorporate viable buffer zone including azonal habitat (which will be specifically protected) to maintain connectivity between large habitat areas and permit recolonization of reclaimed sites.
- Maintain connectivity between on-site conservation areas and Mantadia-Zahamena conservation corridor.
- Crossing structures along mine roads to maintain connectivity between habitat patches and to conservation areas: below road for ground-dwelling fauna and rope bridges for arboreal fauna.

Mitigation Techniques

- The proponent to be active in cooperative forest management and regional resource planning.
- Areas will be progressively mined and reclaimed during operations.
- During Mangoro pipeline construction, open trenches will be limited to short sections and duration to limit trapping animals. Animals that fall into trenches will be captured and released.

Reclamation and Closure

- Work with regional planners to reclaim disturbed areas around the headwaters of the Torotorofotsy basin. Increasing forested cover in this area will enhance faunal movement between the Ambatovy conservation area to Analamay conservation area and beyond to the Mantadia-Zahamena conservation corridor.
- Revegetation with native species.
- Work with other interest groups in support of initiatives in the Torotorofotsy Wetlands and Mantadia-Zahamena corridor to reduce other sources of habitat loss and fragmentation in the LSA.

Impact Analysis

Fragmentation

Results for all indices for each class are provided in the Biodiversity EA (Volume B, Section 4.4). The configuration and distribution of azonal and transitional forests will be the most altered of the habitats in the mine LSA. Construction has resulted in a change from a few, large contiguous patches to more small patches. Although mean nearest neighbour distances have decreased, this has occurred because habitat loss has resulted in a more clumped distribution of the remaining patches. However, these patches are still connected to the zonal forests to the east maintaining connectivity for species, like lemurs, that use various forest habitats.

The change in landscape metrics for ephemeral ponds is a reflection of direct habitat loss; the remaining few, smaller patches largely occur in the on-site conservation areas so are more clumped in distribution than at baseline. The zonal forest is also fragmented, though less so than the azonal and transitional habitats. This result is due to the much wider distribution of this habitat type in the LSA. There are no impacts to the marsh and marsh-edge habitat as a result of the mine activities.

Forested and undisturbed habitats are also both negatively affected by fragmentation due to the project. At impact, these habitats are represented by more, smaller patches. Interpatch distance is larger for the undisturbed habitats, suggesting these patches are less connected. However, connectivity is generally maintained between forested habitats on the east side of the mine, including from the on-site conservation areas through to the Mantadia-Zahamena corridor. Reforestation at the headwaters of the Torotorofotsy basin will further improve connectivity from the Ambatovy conservation area to the main forest corridor.

The proponent is committed to maintain connectivity between primary habitats within the mine areas and to the Mantadia-Zahamena corridor. With successful mitigation (see above), impacts of fragmentation on faunal populations due to site clearing is expected to be low.

Barriers to Movement

The total edge as a result of project activities will increase 13.3% from 580 km to 657 km. The creation of unnatural edges, along with sensory disturbance, will create barriers to movement for fauna in these areas. If the barriers result in the inability of animals to disperse or find mates, the impacts to affected species could affect genetic and demographic attributes of populations. Mitigation,

including on-site conservation areas, maintenance of forested corridors through and around the mine footprint, progressive reclamation and fauna crossing structures, will reduce the magnitude of these impacts.

Residual Impact Classification

Fragmentation

The configuration and distribution of azonal and transitional forests will be the most altered because site clearing will break the azonal complexes at Ambatovy and Analamay into smaller, more separated patches (Volume B, Section 4.4). Fragmentation effects on habitats range from low to high environmental consequence, according to specific habitats (Table 4.2-10). The duration of the effect will be long-term as restoration of habitats will occur post-closure. However, mitigations such as crossing structures and reclamation post-closure will reduce fragmentation effects on habitats.

Table 4.2-10 Residual Impact Classification for Fauna due to Fragmentation and Barriers to Movement

| Taxon | Direction | Magnitude | Geographic Extent | Duration | Reversibility | Frequency | Environmental Consequence |
|------------------------------------|------------------|------------------|--------------------------|-----------------|----------------------|------------------|---|
| Issue: Fragmentation | | | | | | | |
| habitats | negative | low to high | local | long-term | reversible | high | low for most habitats to high for azonal habitats |
| wide-ranging species | negative | low | regional | long-term | reversible | high | moderate |
| forest interior species | negative | low | local | long-term | reversible | high | low |
| other species | negative | negligible | local | long-term | reversible | high | negligible |
| Issue: Barriers to Movement | | | | | | | |
| wide-ranging species | negative | low | regional | long-term | reversible | high | moderate |
| wary species | negative | low | local | long-term | reversible | high | low |
| other species | negative | low | local | long-term | reversible | high | low |

Impacts to fauna are predicted to be greatest for forest interior species, particularly those in azonal and transitional habitats, and wide-ranging species (Table 4.2-10). With successful mitigation, including on-site conservation areas, progressive reclamation, and maintenance and enhancement of forested corridors, the magnitude of the impacts to fauna is predicted to be low.

Barriers to Movement

Barriers to movement are predicted to have a low to moderate environmental consequence for wary and wide-ranging non-flying species (Table 4.2-10). For the latter species, although the magnitude of the impacts is predicted to be low, they can be regional if the population extends beyond the LSA and the ability to disperse and find mates is impaired. For all affected species, the impact duration will be long-term as effects will last until habitats are reclaimed, the effects are reversible if remaining populations can compensate for losses and the frequency is high as barriers can occur continuously. Mitigation, including fauna crossing structures and noise mitigation, will reduce the magnitude of these impacts.

Prediction Confidence

Prediction confidence for changes in landscape indices as a result of fragmentation is medium to high as these impacts were spatially analyzed. However, it is more difficult to determine the actual environmental consequence on fauna, owing to limited understanding of species' ecology. The prediction confidence for faunal effects is medium.

Monitoring

Composition, abundance and distribution of key species will be monitored in the areas around the mine, especially on-site conservation areas, as part of the general fauna monitoring program. In addition, monitoring of crossing structures, previously described, will address the issue of connectivity in and around the mine.

Conclusions

The most highly fragmented habitats as a result of the Ambatovy Project are the azonal and transitional habitats. As connectivity between these habitats and surrounding zonal forests will be maintained, impacts to species that occupy a variety of forested habitats will be reduced.

Impacts to faunal movement due to fragmentation and barriers to movement from mine construction and operation will be greatest for forest interior and wide-ranging species. However, these residual impacts should be low because the proponent is committed to maintaining and restoring connectivity of forested corridors through and around the mine footprint and between the on-site conservation areas and the Mantadia-Zahamena Conservation corridor as part of regional planning initiatives.

4.2.4.4 Key Question W-3 What Effect Will the Project Have on Faunal Health?

Potential Impact Pathways

The potential impacts of the Ambatovy Project on faunal health were qualitatively evaluated through the following two linkages:

- changes in air quality and faunal health; and
- changes in water quality and faunal health.

Air Quality

Uptake of air contaminants via inhalation is typically considered to be minor for fauna compared to uptake of contaminants via the food chain. Amphibians can also be exposed to airborne contaminants through the skin and through changes in aquatic environments. Emissions from diesel-fired generators and mine fleet vehicles will release contaminants which are predominantly airborne oxides of sulphur, oxides of nitrogen and particulates into the environment.

Water Quality

Increased concentrations of compounds or elements can have sub-lethal to toxic effects in fauna, directly and indirectly through ingestion of plants or prey (USEPA 2005).

Assessment Methods

Air Quality

Little information is available on the effects of airborne contaminants on fauna in all habitat types (WHO 2000) and no World Health Organization (WHO) guidelines for airborne contaminants are available for terrestrial fauna. Therefore, WHO guidelines for vegetation were used in the fauna assessment because there is a direct link to fauna through habitat. Potential impacts are discussed qualitatively.

Dispersion of nitrogen oxides (NO_x) and sulphur dioxide (SO₂) were spatially modelled for the mine site based on emissions derived from diesel-fired generators and mine fleet vehicles (Volume B, Section 3.4). Isopleths related to the maximum predicted levels for NO_x and SO₂ were overlain on habitat maps to determine the areal extent across each habitat type. The minimum annual NO_x concentration guideline for vegetation is 30 micrograms/m³ (WHO 2000). The

vegetation guidelines for SO_2 are 10 micrograms/ m^3 for lichens and 20 micrograms/ m^3 for vascular plants (WHO 2000).

The annual average concentrations are the most relevant for evaluating the potential for chronic faunal health risks, since these values represent the long-term average concentrations that fauna may be exposed to on a regular basis within the LSA. Short-term chemical concentrations may only be realized for one hour or one day throughout the year and therefore are not predictive of actual exposures fauna are likely to incur throughout the year.

Water Quality

Information from the Water Quality assessment (Volume B, Section 3.9) was used to help assess the potential impacts to fauna within the mine LSA. Drinking water guidelines for humans (WHO 2004) and aquatic ecosystems (Department of Water Affairs and Forestry 1996) provide general guidelines for fauna. However, some fauna with aquatic larval forms (e.g., amphibians) may be more sensitive to increases in heavy metals such as cadmium (Herkovits et al. 1997). Therefore, a qualitative assessment for sensitive faunal species is provided. Water quality impacts to aquatic fauna, including fish, are addressed in the Human and Ecological Health (Volume B, Section 5.4) and Fish and Aquatic Resources (Volume B, Section 4.3) sections.

Assessment Criteria

The assessment criteria are the same as for direct habitat loss (see Table 4.2-1).

Mitigation

The proponent has incorporated numerous mitigations into the design of the Ambatovy Project to reduce impacts from air emissions and water discharge. These are detailed in the Air and Water Quality sections (Volume B, Sections 3.4 and 3.9).

Impact Analysis

Air Quality

NO_x

After removing all direct effects as a result of site clearing, 3,876 ha (17%) of the mine LSA falls within the NO_x isopleth exceeding the WHO guideline for vegetation of 30 micrograms/ m^3 (WHO 2000). NO_x is predicted to be dispersed over 2,551 ha of zonal forest, 337 ha of azonal habitat and 798 ha of transitional habitat, including the ephemeral ponds in these areas.

The entire Analamay conservation area occurs within an NO_x dispersal zone of 30 micrograms/m³ or greater, with most of this area (92%) within a zone exceeding 60 micrograms/m³ of NO_x. More than half (57%) of the Ambatovy conservation area occurs within an NO_x dispersal zone of 30 micrograms/m³ or greater. A total of 64 ha of this conservation area (31%) occurs within a zone exceeding 60 micrograms/m³ of NO_x. However, it must be noted that the modelling was conducted using the maximum development year with the highest equipment utilization, where in fact the mining activity is phased over several years with varying equipment utilization.

SO₂

The predicted areal extent of SO₂ at the mine exceeding a concentration level of 10 micrograms/m³ is 3,111 ha (14% of the mine LSA) after removing all direct effects as a result of site clearing. The guideline includes the most sensitive plant species and is therefore a conservative assessment.

SO₂ is predicted to be dispersed over 2,206 ha of zonal forest, 325 ha of azonal habitat and 683 ha of transitional habitat, including the ephemeral ponds in these areas.

The entire Analamay conservation area occurs within an SO₂ dispersal zone of 10 micrograms/m³ or greater, with 15% of this area within a zone exceeding 30 micrograms/m³ of SO₂. Almost half (48%) of the Ambatovy conservation area occurs within an SO₂ dispersal zone of 10 micrograms/m³ or greater, with only 3% occurring within a zone exceeding 30 micrograms/m³ of SO₂. As in the case of NO_x, it must be noted that the modelling was conducted using the maximum development year with the highest equipment utilization, where in fact the mining activity is phased over several years with varying equipment utilization.

Water Quality

Based on results from the Water Quality assessment (Volume B, Section 3.9), the predicted levels of chromium during operations in the surrounding watersheds will increase the level of chromium above South African water quality guidelines for aquatic ecosystems including in the Torotorofotsy Wetlands. Cadmium, chromium, lead and zinc may also marginally exceed these guidelines in other local area wetlands during operations. While concentration levels of heavy metals entering aquatic systems from the mine site during the operations period are predicted to be low (i.e., below WHO drinking water guidelines [WHO 2004]), some levels are higher than guidelines set for aquatic ecosystems (Department of Water Affairs and Forestry 1996; see also Volume B, Section

4.1). However, it should also be noted that in some instances, existing baseline levels also exceed the guidelines.

4.2.4.5 Residual Impact Classification

The results of the residual impact classification for faunal health are presented in Table 4.2-11.

Table 4.2-11 Residual Impact Classification for Fauna Health

| Taxon | Direction | Magnitude | Geographic Extent | Duration | Reversibility | Frequency | Environmental Consequence |
|--|-----------|------------|--------------------------|-------------|---------------|-----------|---------------------------|
| Issue: Air quality | | | | | | | |
| species dependent on rare sensitive plants | negative | low | local | medium-term | reversible | medium | low |
| amphibians | negative | low | local | medium-term | reversible | medium | low |
| other species | negative | negligible | local | medium-term | reversible | medium | negligible |
| Issue: Water quality | | | | | | | |
| amphibians | negative | low | local to beyond regional | medium-term | reversible | medium | low |
| other species | negative | negligible | local | medium-term | reversible | medium | negligible |

Air Quality

Despite mitigation, activities related to construction and operation of the mine may result in negative changes to vegetation, including within the on-site conservation areas. Faunal species most likely to be affected include those dependent on rare, sensitive plants in the azonal and transitional habitats and amphibians sensitive to airborne chemicals and potential acidifying effects on aquatic environments. As vegetation impacts are predicted to be low (Volume B, Section 4.1), including within the on-site conservation areas, impacts to dependent fauna are also predicted to be low (Table 4.2-11). Impacts to amphibians due to air emissions are predicted to be low during the dry season and negligible during the rainy season. The impact of air emissions on fauna is reversible since exposures due to the Ambatovy Project will end upon decommissioning.

Water Quality

Increased heavy metals in water can negatively affect the larval development of amphibians, resulting in reduced growth or malformations. As well, there is the

potential for these chemicals to bio-accumulate within wetlands plant tissue (Volume B, Section 4.1) and be ingested by herbivore species, which in turn may be prey to other species. Although water quality parameters may exceed South African guidelines, particularly for chromium, levels are within human drinking water guidelines (Volume B, Section 3.9). Thus, concentrations will likely be too low to cause any adverse effects. These effects will be local in extent and occur continuously over the life of the project. Therefore, the water quality changes are predicted to result in a low environmental consequence to amphibians and negligible for other species.

Prediction Confidence

Prediction confidence for potential impacts to faunal health as a result of changes in air and water quality is medium. Modelled water quality parameters can be well predicted to be below drinking water guidelines. The main reason for the uncertainty is the lack of information in the literature regarding effects of these chemicals on fauna.

Monitoring

The proponent is committed to monitoring the abiotic and biotic environment, particularly within the on-site conservation areas. Water quality monitoring will be conducted throughout the life of the project to ensure that operational controls are achieved and that impacts on downstream concentrations are minimized. Summaries of project-specific air and water controls are presented in the Air Quality (Volume B, Section 3.4) and Water Quality (Volume B, Section 3.9) sections. Periodic faunal monitoring in the conservation areas, including amphibian surveys will be conducted to observe the health of the population to ensure that operational controls are protecting the surrounding areas.

Conclusions

Impacts to faunal health are predicted to be negligible to low as a result of changes in air and water quality. Increases in some heavy metal concentrations are predicted for the mine area, but they are within human drinking water guidelines and are not predicted to adversely affect faunal populations. Source contaminants in water will be monitored along with mobile equipment maintenance to ensure ambient levels do not create adverse effects. In addition, amphibian populations will be monitored along with vegetation and abiotic environmental parameters to observe the health of the natural systems, as another indicator of performance.

4.3 FISH AND AQUATIC RESOURCES

4.3.1 Introduction

This section presents the Environmental Assessment (EA) for the effects of the mine site on fish and aquatic resources, and specifically addresses fish communities, aquatic macro-invertebrates and habitat in compliance with the Ambatovy Project (the project) Terms of Reference.

The EA presents a summary of baseline survey results and issues, followed by the impact assessment. Detailed aquatic resources baseline information is presented in Volume J, Appendix 3.1, Attachments 1, 2 and 3.

4.3.2 Study Area

The primary mine Local Study Area (LSA) for fish and aquatic resources falls within the aquatics study area (Volume A, Figure 7.2-1), and includes the watersheds draining the ore bodies, portions of the Torotorofotsy Wetlands, and the proposed freshwater pipeline from the Mangoro River to the mine site.

4.3.3 Baseline Summary

4.3.3.1 Introduction

The mine study area was surveyed on a reconnaissance inventory level for fish taxa in 1997, with additional limited seasonal sampling for fish, aquatic invertebrates, aquatic macrophytes and general habitat characteristics in 1998 (Volume J Appendix 3.1, Attachment 3). Programs in 2004 and 2005 extended the sampling to additional sites during both wet and dry seasons, including fish and aquatic invertebrate communities and aquatic habitat characteristics (Volume J, Appendix 3.1, Attachments 1 and 2).

4.3.3.2 Methods

The overall objectives of the sampling program in the mine LSA were to:

- map and describe the aquatic habitat in LSA watercourses and water bodies;
- inventory aquatic communities to determine species richness, diversity, distribution, relative abundance and key habitats of fish and benthic macro-invertebrates;

- document the presence of endemic or listed species and identify potential conservation issues; and
- describe the local use of fish for commercial and traditional purposes.

As the project ore bodies lie generally on a high plateau and a drainage divide, the headwaters of several drainage basins originate within the mine LSA. Sampling sites were selected in each of the drainages likely to be affected by activities associated with the mine operation. Site selection was based on representativeness (sites included the most dominant habitat types within a reach), proximity to hydrological and water quality stations, and accessibility. Ten sites, comprising four ephemeral pools and six streams/rivers, were sampled during the 1998 reconnaissance survey. During the 2004-2005 detailed surveys, a total of 19 sites, comprising 16 located on streams/rivers (including one 1998 site) and three ephemeral pools (including one 1998 site) were sampled (Volume J, Appendix 3.1, Attachment 1, Figure 1).

Aquatic Habitat

Two approaches were used to assess habitat quality and quantity during field studies. First, 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. Second, the Intermediate Habitat Integrity Assessment (IHIA) model (Kemper 1999) was used to describe and quantify habitat characteristics.

Fish Sampling

Fish samples were collected using a variety of techniques in order to sample all habitat types used by the resident fish species. Electro fishing, seine nets, and gill nets were the primary methods; in addition, cast nets were used in deeper water during the 1998 survey and to collect food fish for contaminant analysis in 2005. 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 through the Biology Department, University of Antananarivo. Confirmation of these identifications is in progress through 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-Invertebrate Sampling

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; these have been archived for future analysis.

Resource Use

Information on artisanal fisheries in the project area was collected on an opportunistic basis by observations or conversations with residents within the locations 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.

4.3.3.3 Results

Aquatic Habitat

Generally, lower order stream sites in the mine LSA were shallow and flow rates were low. Only a limited number of sites (larger rivers) contained deeper habitats. The pH was typical of water bodies in the Ambatovy area and ranged from slightly acidic (5.3) to neutral (7.3). The most prevalent substrate types were combinations of mud/silt, gravel/cobble, or fines/organic material. Instream cover varied between sites and habitat condition, but generally was dominated by small and large woody debris, leaf litter and undercut banks.

Based on the IHIA classification of habitat quality and quantity, nearly 50% of the sites in the LSA were natural or largely undisturbed (IHIA Classes A and B;

Table 4.3-1 and Figure 4.3-1). A majority of the natural, undisturbed, sites occurred in the headwater sites of watersheds draining the mine area (1st, 2nd and 3rd order streams).

Within the Torotorofotsy Wetlands (seven sites) aquatic habitats generally exhibited significant disturbance and loss of natural ecosystem function (IHIA Classes D, E and F). Only two sites on small inflowing tributaries displayed natural, unmodified, conditions.

Table 4.3-1 Habitat Characteristics of Stream Sample Sites in the Mine Local Study Area

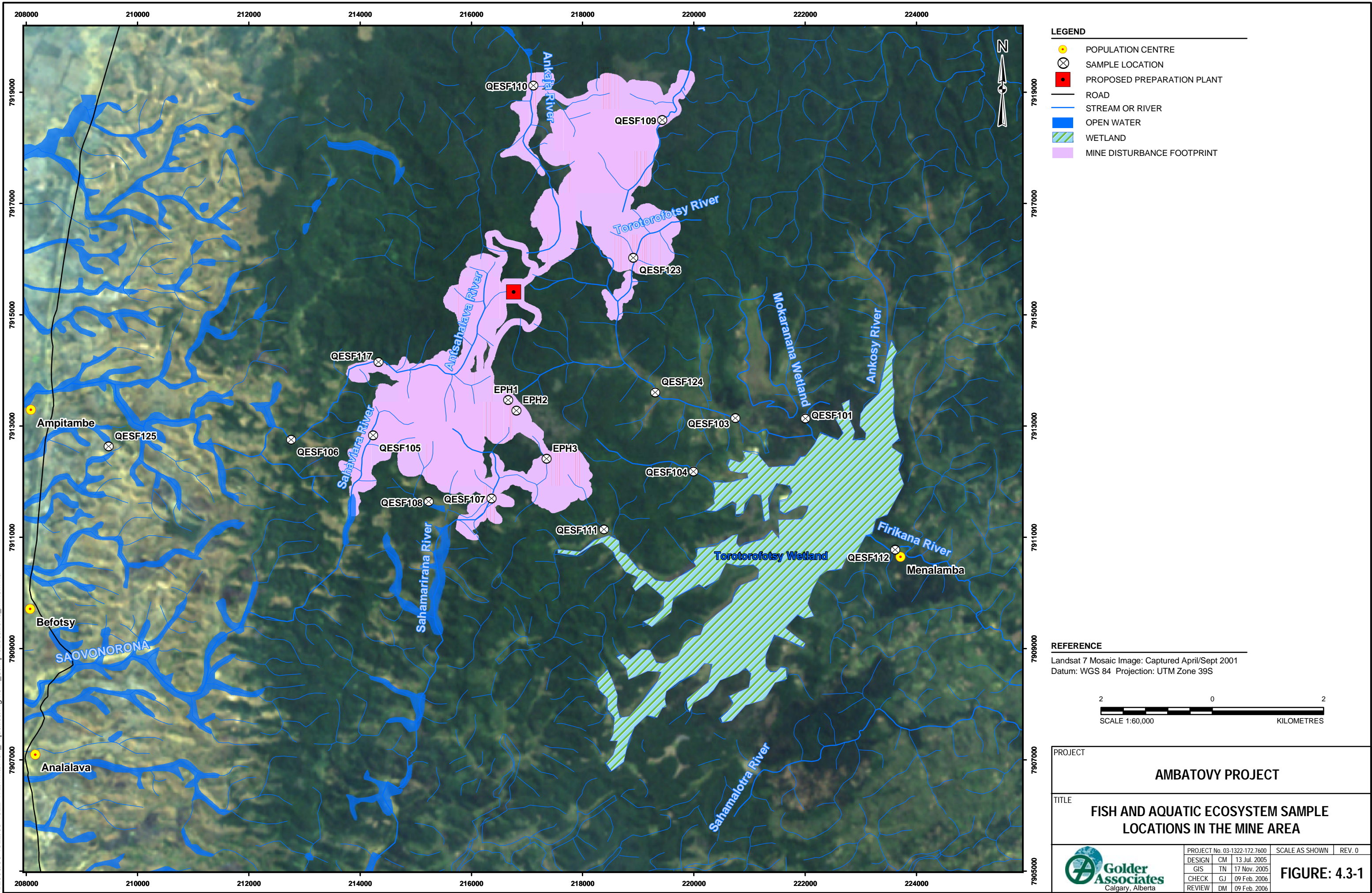
| Site | IHIA Class ^(a) | Habitat Description |
|----------------------|---------------------------|--|
| QESF101 ^T | D | Largely modified, loss of natural habitat, biota and ecosystem function. Major threats are bed modification due to deforestation and exotic fish species. |
| QESF103 ^T | D | Largely modified; similar to preceding site. |
| QESF104 ^T | A | Unmodified habitat, minimal deforestation in surrounding catchment. Some riparian invasion with exotic aquatic plants. |
| QESF105 | A | Unmodified habitat, minimal deforestation in surrounding catchment. |
| QESF106 | B | Largely unmodified. Minor changes in natural habitat and biota but basic ecosystem functions unchanged. |
| QESF107 | F | Critically modified. Bed and channel modification due to conversion of adjacent wetland into paddy rice fields. Exotic plant growth in stream channel. |
| QESF108 | E | Extensively modified with loss of natural biota and ecosystem function. |
| QESF109 | A | Unmodified primary forest area. |
| QESF110 | A | Unmodified primary forest area. |
| QESF111 ^T | F | Critically modified. Major impacts are deforestation in catchment and creation of wooden weir across stream resulting in increased turbidity and sedimentation. |
| QESF112 ^T | C | Moderately modified. Loss of natural habitat and biota, but basic ecosystem functions remain predominantly unchanged (moderate size river site; Torotorofotsy Wetlands outflow). |
| QESF115 | D | Large-scale loss of natural habitat, biota and ecosystem function (Mangoro River; large river site). |
| QESF117 | A | Unmodified habitat. Some riparian zone invasion with exotic plants. |
| QESF123 ^T | A | Unmodified, natural habitat. |
| QESF124 ^T | E | Extensively modified with loss of natural biota and ecosystem function. |
| QESF125 | E | Extensive modification of bed, channel, flow regime and presence of exotic fish species. Indigenous vegetation entirely replaced by exotics (large stream site). |
| EPH1 | n/a | Located in a moderately to highly degraded area. |
| EPH2 | A | Unmodified habitat. No evidence of human impact. |
| EPH3 | A | Unmodified habitat. Limited human impact. |

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

T Torotorofotsy Wetlands tributary.

n/a Not applicable.

I:/2003/03-1322/03-1322-172/mxd/Fish_Aquatics/Fig4.3-1_SampleLocations_Mine.mxd



Fish

Fifteen fish species were collected from the mine LSA during the 1998 and the 2004-2005 surveys and comprised three endemic, eight introduced, and four native species (Table 4.3 - 2). A fourth endemic, a new species of *Rheoclès* (*R. "Ambatovy"*), may also be present in the LSA (pers. comm., P. Loiselle; reported in Sparks and Stiassny 2005).

Table 4.3-2 Fish Species Recorded at the Mine Local Study Area During the 1998 and 2004-2005 Surveys

| Family | Species | Origin | Conservation Status ^(a) | IUCN Status ^(b) |
|----------------------------|---|--------|------------------------------------|----------------------------|
| Anguillidae | <i>Anguilla mossambica</i> | N | S | nl |
| Atherinidae ^(c) | <i>Atherion</i> sp. | N | S | |
| Cyprinidae | <i>Carassius auratus</i> | I | | |
| Gobiidae | <i>Chonophorus aeneofuscus</i> | N | S | nl |
| Gobiidae | <i>Glossogobius giuris</i> | N | S | nl |
| Anabantidae | <i>Ctenopoma ansorgii</i> | I | | |
| Belontiidae | <i>Macropodus opercularis</i> | I | | |
| Channidae | <i>Channa maculata</i> ^(e) | I | | |
| Cichlidae | <i>Oreochromis niloticus</i> | I | | |
| Cichlidae | <i>Tilapia zillii</i> | I | | |
| Eleotridae | <i>Ratsirakia legendrei</i> | E | T | DD |
| Eleotridae | <i>Ratsirakia</i> sp. | E | nl | nl |
| Bedotiidae | <i>Rheoclès alaotrensis</i> | E | T | VU |
| Bedotiidae | <i>Rheoclès "ambatovy"</i> ^(d) | E | nl | nl |
| Poeciliidae | <i>Xiphophorus maculatus</i> | I | | |
| Poeciliidae | <i>Gambusia holbrooki</i> | I | | |

Notes: E = endemic, I = introduced, N = native; S = secure, T = threatened.

IUCN status: nl = not listed, DD = data deficient, VU = vulnerable.

(a) Sparks and Stiassny (2003).

(b) International Union for the Conservation of Nature (IUCN) Red List (2004).

(c) From 1998 survey only (Sparks et al. 1998).

(d) Unconfirmed.

(e) Misidentified as *Ophicephalus striatus*.

Except for one species (*Atherion* sp.) in the family *Atherinidae*, all other seven species reported in 1998 were confirmed during the 2004-2005 seasonal surveys. Generally, species diversity was low and abundances were moderate. The highest diversities occurred at sites QESF112 and QESF125 with seven species each. Although no clear pattern emerged between diversity and habitat characteristics, the high diversity at these two sites may be associated with heterogeneity in

habitat type resulting from high variation in instream cover (QESF112) and channel size. QESF125, located on Sahaviara River and QESF115, on the Mangoro River were the only large river sites sampled. No significant temporal difference in species associations was observed between high flows and low flows, indicating possibly little seasonal movement or migration, at least within the smaller streams which predominated in the study area.

Generally, the endemic fish species dominated in undisturbed habitats, occurring at >60% of sampling sites. In contrast, introduced species, such as the *anabantid*, *Ctenopoma ansorgii*, and the *poecelid*, *Xiphophorus maculatus*, were more prevalent in disturbed areas. In addition to habitat degradation due to deforestation, endemic species are threatened by competition from introduced species, in particular from *Xiphophorus maculatus*. Also of concern was the presence of *Channa maculata* (blotched snakehead), encountered only in the two large river sites sampled in the Mangoro drainage. This fish is an introduced voracious predator, which has had major impacts on native fish populations in Madagascar (Sparks and Stiassny 2003).

All fish encountered in the streams are relatively small-bodied species, and are not highly used for food fish. However, the wetlands areas or larger downstream water bodies may contain fish populations of importance (i.e., exotics such as *Tilapia* sp.) for artisanal fisheries.

Aquatic Macro-Invertebrates

A total of 70 macro-invertebrate taxa were recorded in the mine LSA during the 2004-2005 survey. All taxa recorded in 1998 were confirmed during the 2004-2005 survey (Table 4.3-3). In contrast to the fish fauna, both diversity and abundances of the macro-invertebrate fauna were high. However, similar to fish fauna, aquatic macro-invertebrate diversity and abundance were generally higher at undisturbed primary forest sites than deforested locations; the highest species richness (51) was recorded at site QESF110 in an undisturbed primary forest. The ephemeral ponds were fishless but contained a unique assemblage and diversity of macro-invertebrates and plankton.

Endemic and Native Species

Fish

The fish fauna within the mine LSA contains four endemic fish (*Rheoclès alaotrensis*, *Ratsirakia legendrei*, one suspected new undescribed *Ratsirakia* species and the suspected *Rheoclès* “Ambatovy” species). These fish belong to one of the two freshwater fish families endemic to Madagascar, the *Bedotiidae* or Malagasy Rainbowfishes, with two genera (*Bedotia* and *Rheoclès*).

Table 4.3-3 Aquatic Invertebrate Taxa Present at the Mine LSA; 2004-2005 Survey

| Order | Family | Order | Family |
|----------------------------|-------------------|----------------------------|-------------------|
| ARHYNCHOBDELLIDA | Hirudidae | GASTEROPODA ^(a) | Planorbidae |
| BASOMMATOPHORA | Physidae | | Thiaridae |
| COLEOPTERA | Dryopidae | BIVALVIA | Sphaeriidae |
| | Dysticidae | HEMIPTERA | Aphelocheiridae |
| | Elmidae | | Corixidae |
| | Gyrinidae | | Gerridae |
| | Helophoridae | | Mesoveliidae |
| | Hydraenidae | | Naucoridae |
| | Hydrophilidae | | Nepidae |
| DECAPODA | Astacidae | | Notonectidae |
| | Atyidae | | Veliidae |
| | Grapsidae | LEPIDOPTERA | Pyrilidae |
| | Palaemonidae | MEGALOPTERA | Sialidae |
| | Parastacidae | ODONATA | Aeshnidae |
| | Potamonautidae | | Calopterygidae |
| DIPTERA | Athericidae | | Coenagrionidae |
| | Ceratopogonidae | | Corduliidae |
| | Chironomidae | | Gomphidae |
| | Culicidae | | Lestidae |
| | Dixidae | | Libellulidae |
| | Empididae | | Platycnemididae |
| | Simuliidae | OLIGOCHAETA | Lumbriculidae |
| | Tipulidae | PLECOPTERA | Notonemouridae |
| EPHEMEROPTERA | Baetidae | TRICHOPTERA | Beraeidae |
| | Caenidae | | Ecnomidae |
| | Ephemerellidae | | Glossosomatidae |
| | Heptagenidae | | Hydropsychidae |
| | Leptophlebiae | | Hydroptilidae |
| | Oligoneuridae | | Lepidostomatidae |
| | Polymitarcidae | | Leptoceridae |
| | Prosopistomatidae | | Philopotamidae |
| | | | Polycentropodidae |
| GASTEROPODA ^(a) | Bithyniidae | MERMITHOIDAE | Psychomyiidae |
| | Bythinellidae | | Sericostomatidae |
| | Hydrobiidae | | |
| | Lymnaeidae | | Mermithidae |

^(a) Gasteropoda is a class.

Rheocles alaotrensis exhibited a relatively wide distribution and moderate abundance in the mine LSA, It occurred at 2 of 6 and 10 of 16 permanent water body sites sampled in 1998 and 2004-2005, respectively. Generally, abundance

was high at undisturbed primary forest sites (clear and silt free waters) and low at deforested or modified locations.

Ratsirakia legendrei also occurred at 2 of 6 and 10 of 16 permanent water body sites sampled in 1998 and 2004-2005, respectively. It was the most abundant endemic species at most sites and often exhibited the highest relative abundance of all species collected. At the headwater sites on the Ankaja and Sakalava rivers, it was the only species present during wet season surveys. Prevalent at undisturbed habitat sites, it often occurred in association with *R. alaotrensis* and was typically less abundant at sites dominated by the introduced species *C. ansorgii* or *X. maculatus*. Within the mine LSA, an unidentified *Ratsiraka* species was also captured at two sites (QESF 109 - Sakalava River and QESF 104 – Torotorofotsy inlet tributary).

Four native fish (*Anguilla mossambica*, *Chonophorus aeneofuscus*, *Glossogobius giurus*, and *Atherion* sp.) were also recorded in the mine LSA. The native *Anguilla mossambica* (eels) was captured in the headwaters of the Torotorofotsy, Ankaja and Sahamarirana rivers within the study area, illustrating its extensive upstream migrational capability (from the Indian Ocean).

Aquatic Invertebrates

A large number of endemic aquatic macro-invertebrate taxa are present in the streams within the LSA; however the current level of identification limits the description of taxa for this report. Several of the more significant groups in the community were:

Atyidae (freshwater shrimp); these have a high degree of endemism (77%), with 26 species in four genera existing on the island (Raharivololoniaina 2004). Within the mine LSA, they were the most abundant taxa in Group I (similarity analysis) during the wet season survey.

Plecoptera (stoneflies) are represented in Madagascar by only one family with one endemic genera (*Madenemura*). It is found in small streams and rivers at altitudes of 750 m or more, and water temperature less than 18 °C. Two undetermined specimens were collected during the dry season survey from the mine area; one specimen was collected during the wet season survey.

Polymitarcyidae (mayflies) is represented in Madagascar by the single genus *Probosciodoplocia* which is strictly endemic and composed of at least seven species. It is one of the largest mayflies in the world. It was the most abundant taxa in Group IV (similarity analysis) during the high flow survey and was encountered in the two pristine forest sites draining from the Analamay ore body.

The *Odonata* (dragonflies) with eight families, was also common in the LSA. Madagascar is one of four smaller islands in the world noted for their rich *Odonata* fauna. The number of endemic species and genera of the *Odonata* in Madagascar are remarkable. Of 52 genera, 12 are endemic; of the 181 named species and subspecies, 132 are endemic and most of the endemic species are concentrated on the forested eastern edge of the island (Donnelly and Parr 2003).

Unique and Sensitive Aquatic Habitats

Unique aquatic habitats and ecosystems identified in or associated with the mine area were the Torotorofotsy Wetlands and the ephemeral ponds. The headwater forest streams draining the ore bodies also present locally significant habitats.

The ephemeral ponds on the Ambatovy and Analamay plateaus are unique water bodies. Their location on the ferricrete creates special hydrologic properties, including their seasonal and ephemeral nature, making them a rare aquatic habitat type. Although they do not provide fish habitat, they provide unique conditions for other aquatic fauna and flora including aquatic macro-invertebrates, zooplankton and aquatic macrophytes that depend on seasonal water for critical habitat to complete their life cycle. The aquatic invertebrate communities identified in these ponds were quite distinct from other communities in the LSA in terms of community structure and species composition.

The streams and rivers within the mine disturbance area contain the headwaters of six watersheds. A majority of the headwaters within the mine disturbance area contain 1st and 2nd order streams, but also include upper reaches of 3rd order rivers. Many of the 1st order streams originate in the azonal area, either from seasonal surface flow or groundwater (springs) and then continue as 2nd and 3rd order streams within the transitional and zonal forest.

The 1st order streams surveyed to-date do not appear to support year-round use by fish. However, they are used by aquatic macro-invertebrate species and periphytic algal species adapted to the flow regime and channel morphology, and contribute as sources of food for downstream consumers. Some of these species may not yet be described.

A majority of the 2nd and 3rd order streams within the mine area are headwater refugia for populations of endemic and IUCN listed fish species (*Ratsirakia legendrei*, *Ratsirakia* sp (unidentified) and *Rheoclela alaotrensis*) or native fish species with only a few exotic species present, primarily in disturbed portions of the drainages. Because these streams and rivers are the headwaters for a large surrounding region, and depend upon the geologic substrate structure and surface features of the unique azonal and zonal forest area for their hydraulic,

morphologic and riparian characteristics, they are considered sensitive aquatic habitat.

Systems draining to the Torotorofotsy Wetlands are important for their role in maintaining and regulating the water levels and water quality of the marsh system. The Torotorofotsy Wetlands is a unique ecosystem in the region and in Madagascar. It is considered one of the most valuable ecosystems in the study area because of its ecological function and biodiversity, and has recently been declared a Ramsar Site (see Volume B, Section 4.5).

The ecology and biology (habitat diversity, habitat continuity, critical habitats for reproduction) of the Torotorofotsy Wetlands is sensitive to water level and water quality fluctuations. The Torotorofotsy Wetlands and adjacent marshes, especially Mokaranana, contain valuable communities of mid-altitude marsh fauna. This includes a mixed taxonomic community of resident and transient marsh birds, fish, invertebrates and small mammals. Populations of important regionally endemic fish species (either *Rheocles alaotrensis* or *Ratsirakia legendrei*) were present in all wetlands-associated sampling sites. However; although unique and sensitive, the Torotorofotsy Wetlands is not pristine habitat. It exhibits considerable habitat disturbance along the marsh edge and in the watersheds (an abandoned railway across the northern end, moderate to heavy logging, disturbed marsh edge from agriculture and grazing, and watercourse manipulation for rice production) and consequently several exotic fish species have already invaded portions of the wetlands and moved upstream into tributary drainages.

4.3.4 Issue Scoping

4.3.4.1 Issues and Key Questions

The primary issues identified with respect to the potential impact of the project on the aquatic biota and environment in the mine area are:

- Loss (potential extirpation or extinction) of locally endemic fish or important aquatic invertebrate species as a result of the removal or disturbance of aquatic habitat in streams and wetlands by mine construction and operation and elimination of the local population of the species in these habitats.
- Riparian habitat degradation (loss of vegetation canopy food source and instream habitat features) and impairment of stream water quality (sedimentation) as a result of deforestation and disturbance to forest stream ecosystems associated with development of the mine and ancillary facilities.

- Environmental stress to the life history of fish and aquatic biota, and critical habitat functions, as a result of alterations to seasonality of stream flow (increased or decreased runoff to nearby water bodies) due to changes in hydrologic characteristics of drainage areas, streams and wetlands disturbed by construction and operation of the mine.
- Water quality changes during construction and operation of the mine affecting the abundance, health and survival of endemic fish and aquatic fauna both onsite and in downstream drainages, including the Torotorofotsy Wetlands. This issue was a main one raised during consultation (Volume A, Section 6).
- Increased potential for establishment of non-indigenous fish species and invertebrates as a result of habitat alterations, and the displacement of endemic biota.
- New or improved access to streams and wetlands in the project area and region resulting in increased human activity and increased harvest of fish for consumption or trade and/or introduction of exotic species.
- Entrainment of fish and invertebrate fauna by the Mangoro River water intake resulting in local mortalities and also potential for introduction of non-indigenous species to the eastern drainages of the mine area.
- Loss of aquatic habitat in the Mangoro River as a result of water withdrawal and instream flows alterations.
- Changes in fish health as a result of the construction and operation of the mine, production area facilities and associated infrastructure.
- The effectiveness of post-closure aquatic habitat and biota reclamation or compensation.

These issues and impacts have been addressed in the following analysis by a focused set of 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, Survival of Endemic or Native Species and Community Structure? |
| 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 mine and facilities, as illustrated in the linkage diagram (Volume H, Appendix 9).

4.3.4.2 Assessment Parameters

Aquatic biota of significance to the proposed project includes both the fish and invertebrates (i.e., benthos, zooplankton and phytoplankton) that form part of the aquatic ecosystem in the mine 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, key species of concern, significant species groups and sensitive habitat types were selected for specific focus during the impact assessment and development of mitigative strategies. The selected species groups and habitats for the mine area are:

- endemic fish species;
- macro-invertebrate communities (containing endemic or native species);
- headwater stream habitats (1st, 2nd and 3rd order streams); and
- ephemeral ponds.

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.

Extensive use was also made of the conclusions of the surface water, groundwater, water quality investigations and the preliminary design for the mine and support facilities.

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 mine site activities during construction, operation and closure phases. Habitats can also be affected by ancillary facilities and services such as watercourse crossings by access roads and the Mangoro river water pipeline. Changes in the availability, quality or quantity of fish and aquatic habitat may result from:

- riparian clearing;

- physical removal or disturbance of instream habitat (stream channels or ponds);
- changes in water flow downstream; and
- changes in surface water quality.

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, ephemeral ponds, endemic fish, benthic macro-invertebrates | <ul style="list-style-type: none"> - stream order and exclusion length - pond number and area - water flow and prediction of fish habitat based on estimated area - reclamation habitat type | <ul style="list-style-type: none"> - net 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 | <ul style="list-style-type: none"> - fish/ invertebrate community structure and diversity - results of physical habitat and aquatic health assessments - plant operations, water intake, tailings discharge - potential for transfer of fish and biota ; harvest pressure | <ul style="list-style-type: none"> - subjective evaluation of sustainability of the resource; professional judgment - conservation status (IUCN 2004 and published checklists) - intake screening design considerations - water quality guidelines for the protection of aquatic life (CCME 1999) - watercourse crossings design considerations |
| change in fish health, quality and use | artisanal fisheries | <ul style="list-style-type: none"> - surface water quality and prediction - metal concentrations in baseline fish tissue - predicted fish abundance | <ul style="list-style-type: none"> - World Bank Environment, Health and Safety Guidelines for Mining and Milling – Open Pit - suggested values from the literature - subjective evaluation and professional judgment |

Riparian Vegetation Removal

Clearing of riparian vegetation, associated forest canopy 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. A majority of riparian clearing will occur during mine construction and expansion and is directly linked to removal of the local area stream channels and ponds (below). Riparian disturbance will also occur during construction of the water intake (Mangoro River) and the water pipeline watercourse crossings.

Removal and Disturbance of Stream Channels and Ponds

Removal and drainage of existing stream channels and ponds (either permanent or ephemeral) is one of the most severe habitat losses as it permanently eliminates the mine site 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 mine construction and expansion (operations), access road and water pipeline construction.

Changes in Water Flow Downstream

Change in water flow (surface water or groundwater) will occur during construction and operation, headwater streams will be disturbed and a portion of the water diverted to mine area containment ponds. Increased flows will also occur from disturbed areas where vegetation is removed. Flow releases to downstream reaches of the local watersheds will be controlled; these releases can affect the use of downstream habitats by aquatic biota. Stream and wetlands fish and macro-invertebrate species may be affected. Downstream water flow in the Mangoro River, and potential habitat quantity and utilization, may be impacted as a result of water abstraction for the mine.

Changes in Surface Water Quality

Changes to surface water quality (i.e., sediments, temperature) will occur as a direct result of runoff from mine site clearing, riparian vegetation removal and surface water management (including containment ponds) on the mine disturbance area. Water quality may also be affected by instream activities during construction of ancillary facilities and by local air quality. Changes in water quality may directly or indirectly affect fish and aquatic biota, and the productivity of aquatic habitat.

4.3.5.2 Assessment Methods

Riparian Habitat

Equivalent values for riparian clearing were assumed similar to linear values of baseline stream channel lengths affected by the total footprint of the mine disturbance area, as measured by geographic information system (GIS) analysis. Access road and pipeline riparian areas were assessed from map data and an enumeration of potential watercourse crossings. No attempt was made to determine the aerial extent of riparian vegetation (i.e., width along channels), thus this assessment is viewed as qualitative and very conservative. A habitat integrity assessment, which included riparian and instream criteria was used to

classify the extent of existing disturbance (Volume J, Appendix 3.1, Attachment 1).

Removal of Stream Channels and Ponds

The total linear value of all stream channels, by order, lost to the footprint of the mine disturbance area and channels disturbed (i.e., fragmented or flows directly altered) was determined by GIS measurement. The number and aerial extent of ephemeral ponds within the mine area was also determined by GIS analysis 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 at field sample sites. Disturbance and alteration of aquatic habitat along the water pipeline was assessed from map data and enumeration of watercourse crossings.

Changes in Water Flow Downstream

Changes in water flow downstream were examined for the six watershed areas in the mine area, as provided within the Hydrology Section (Volume B, Section 3.8). Impacts on aquatic habitats, fish communities and aquatic invertebrate species identified during the baseline survey were discussed qualitatively.

Water will be pumped from the Mangoro River for ore preparation. Potential effects were qualitatively assessed based on the hydrology assessment and professional judgment based on existing instream flow information.

Changes in Surface Water Quality

Predicted changes in water quality (Volume B, Section 3.9) and hydrogeology (Volume B, Section 3.7) were examined for the six watershed areas in the mine area and the watercourses along the access roads and water pipeline. 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 regional study area (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 ponds, change in hydrology and changes to water quality include the following:

Design Features

- The project area footprint will include two areas of protected azonal forest habitat and thus avoid a total loss of sensitive aquatic habitats. The Ambatovy area will contain six of the remaining eight ephemeral ponds in the study area, and also offer protection to portions of seven headwater azonal transitional 1st order streams. The Analamay protected area provides some headwater primary forest protection near the Sakalava watershed.
- Disturbances by sedimentation or water quality effects to the Torotorofotsy watershed will be minimized to protect sensitive habitats in the Torotorofotsy Wetlands and maintain existing ecosystem conditions.
- The mine water management plan will use variable instream flow releases to simulate seasonal magnitude and duration of natural flows, and therefore maintain natural ecosystem functions and aquatic biodiversity.
- Watercourse crossing guidelines and eco-plans will be implemented to minimize in-water work and disturbance of aquatic /riparian habitat, and control sediment levels.
- Work closely with interest groups to align initiatives with their regional conservation plans.

Reclamation

- Re-establish forest cover and riparian habitat along rehabilitated watercourses or standing water bodies in the mine area at closure.
- Immediate revegetation of all disturbed riparian habitats at road and /or water pipeline watercourse crossings.
- On-site drainage restoration and establishment of end-pit water bodies and connector streams.

Compensation

- An off-site azonal conservation area is to be conserved, which includes ponds and other aquatic habitat (Volume B, Section 4.1).

4.3.5.5 Results

Riparian, Stream Channel and Pond Displacement

Mine Disturbance Area

The footprint of the mine disturbance area will result in the physical loss of stream and riparian habitat; much of this being headwater azonal and transition forest stream habitat.

Streams and ephemeral ponds within six watersheds will be directly disturbed by channel or flow removal, or indirectly severely disturbed in immediate downstream reaches of the watershed by diversion of a majority of baseline flow during construction of the mine. The extent of watercourse and ephemeral pond loss and displacement is summarized in Table 4.3-6.

An estimated total of 10.5 ha of stream habitat (instream wetted area) within 76.0 km of channel will be removed by the mine. This represents about 45% of the channel length within the local mine-area watersheds of the Torotorofotsy, Sahamarirana, Antsahalava, Ankaja and Sakalava rivers. The greatest impact on streams within the immediate disturbance area will be to the small headwater 1st order streams, which make up 76% of the watercourses, with a total direct loss of 49.0 km of channel length (estimated 2.9 ha wetted channel area) and potentially a similar, but unquantified, amount of riparian buffer habitat. Many of these watercourses do not support fish populations because of habitat limitations (high gradients, movement barriers, ephemeral flows, shallow depths, etc.), but do contain undescribed communities or species of aquatic macro-invertebrates and flora (algae / periphyton), and provide a source of food items (aquatic and terrestrial) for downstream fish and invertebrate communities. They also provide an important influence on downstream aquatic habitat quality through flow

volume and physical or chemical characteristics (i.e., water temperature, oxygen, sediment and nutrients).

A total of 16.2 km (estimated 4.3 ha wetted channel) of 2nd order stream will be directly lost to mine disturbance; while 10.8 km (estimated 3.3 ha wetted channel) of 3rd order stream will also be lost. These slightly larger streams generally contained important fish and invertebrate communities and contained both natural and disturbed habitats (Volume J, Appendix 3.1, Attachment 1, Table 10). A majority (70%) of 2nd and 3rd order streams were classified as natural (IHIA Class A) or largely natural with few modifications (IHIA Class B) based on habitat integrity assessments (Kleynhans 1996) of the aquatic and riparian habitats.

Table 4.3-6 Aquatic Habitat Loss as a Result of the Displacement of Streams and Ponds by Mine Disturbance^(a)

| Habitat Type | Number and Mean width (m) | Channel Length (m) | Est. Wetted Area (ha) |
|-------------------|---------------------------|--------------------|-----------------------|
| Streams 1st order | 73 (0.55) | 48948.44 | 2.92 |
| Streams 2nd order | 16 (2.63) | 16226.96 | 4.27 |
| Streams 3rd order | 7 (3.06) | 10790.18 | 3.30 |
| Ephemeral Ponds | 22 | - | 4.09 |

^(a) Within mine footprint and boundaries of watersheds (Ankaja, Sakalava, Torotorofotsy, Antsahalava, Sahamarirana and Sahaviara) affected by removal of channels, flows, connectivity and ponds.

Analysis of fish species composition at the sample sites correlated the presence of predominately indigenous (endemic and native) fish species to the presence of largely natural forest stream habitat. Habitat loss and alterations will jeopardize existence of these populations. The remaining sites (30%) in the direct mine disturbance area displayed moderate to critical levels (IHIA Classes C to F) of existing habitat disturbance, with a mixture of indigenous and exotic fish species.

The footprint of the mine will eliminate a majority (22 of 30) of the ephemeral ponds unique to this area. However, six of the ponds remaining outside of the mine area are in the proposed Ambatovy azonal conservation area. In addition, similar looking ponds have been found in the proposed off-site azonal conservation area, which holds promise for additional off-site conservation of this rare pond ecosystem (Volume B, Section 4.1). Although it does not appear that fish use these water bodies, diverse and possibly un-described populations of aquatic macro invertebrates and plankton use the ponds in addition to their potential role for semi-aquatic or terrestrial and avian fauna.

Water Pipeline and Access Roads

Ancillary facilities (i.e., the Mangoro River water pipeline, haul roads and access roads) may potentially disturb riparian and aquatic habitat and fauna in study area watercourses by instream activities and by surface runoff (i.e., sediment from erosion). Along the proposed water pipeline route, 11 permanent watercourses will be crossed. However, effects on aquatic instream habitat will be temporary. A majority of these watercourses are located in disturbed habitats.

Assuming open cut installation of the water pipeline, effects will be primarily a short-term disturbance of riparian and instream habitat and limited to the construction period, with negligible impacts. The effects of any service road construction will be similar; however long-term, permanent disturbance could occur depending on the type of road crossing (culvert, bridge, water ford).

In addition, an undefined amount of riparian and instream habitat will be disturbed in the Mangoro River as a result of the water intake and pumphouse construction. Disturbance will be primarily temporary (construction); however some long-term loss will occur as a result of the footprint of the water intake. This is expected to be small in area, and as aquatic habitat in the Mangoro River was rated as HIHA Class D (largely modified) it is expected to exhibit a low sensitivity to construction and habitat loss.

Change in Downstream Water Flow and Quality

Instream Flow Changes

The mine water management plan will use containment ponds, located at the perimeter of the mine, to intercept mine site runoff waters. These ponds are designed to settle suspended matter prior to discharge to the downstream drainage basins. The ponds can also be used to supplement ore process plant water requirements and to help augment and regulate downstream flows.

During construction of the mine some short-term impacts from downstream flow and water quality changes may occur in aquatic habitats as water management infrastructure is developed.

During mine operations, the water management plan will maintain flows. The ponds will be operated so that the outflows minimize downstream impacts relative to flow and quality, as discussed in the hydrology assessment, Volume B, Section 3.8. However, it is predicted that there will be an increase in wet season flows, owing to vegetation removal at the mine and increased run-off.

Increases in flow will vary within the basins and mine operational period, but generally should not exceed 20% above baseline within the reach immediately below the containment ponds (i.e., within 500 m) and are rapidly attenuated downstream as additional tributary inflows occur. The increase in flow during operations and closure will slightly alter other physical aquatic habitat parameters, with slight increases in water depth, wetted channel area and velocity (Tables 3.8-11 and 3.8-12; Volume B, Section 3.8, Hydrology).

The modifications to the watershed by the mine will result in some changes to the aquatic ecosystem and potentially to ecosystem function. However, implementation of an instream flow process which provides for seasonal flow patterns is expected to largely maintain existing aquatic communities and habitat diversity, and any downstream impacts from mine-related flow alterations are considered low in magnitude.

For the Mangoro River water pipeline, the hydrology assessment predicted a reduction of 0.3% of average annual flow and a maximum of 1.4% of the lowest recorded 10 year flow in the river. These changes in flow volumes are unlikely to have a measurable effect on aquatic habitat or use of the river by existing aquatic communities.

Water Quality Changes

Water quality changes affecting aquatic habitat in the mine area will be primarily associated with instream work activities, erosion (sedimentation) during surface water runoff, releases from containment ponds, and groundwater affected by mine materials.

Increased turbidity and sedimentation during construction are the primary water quality changes which may affect aquatic ecosystems along the water pipeline, access or service roads, and the water intake. The application of designed sedimentation and erosion control systems during construction will minimize potential effects and impacts will be low.

4.3.5.6 Impact Analysis

Residual Impacts

Residual impacts of aquatic habitat loss as a result of the Ambatovy Project mine site construction operation and closure are summarized in Table 4.3-7.

The status of aquatic habitat in the mine area is moderately well understood, but the level of baseline information for some sensitive habitats (ephemeral ponds,

1st order streams and the Torotorofotsy Wetlands) is low. The prediction confidence for impact ratings for habitats within the mine disturbance area is high, as there is very limited potential for mitigation. The prediction confidence for impact ratings for habitats downstream, in particular the Torotorofotsy Wetlands, is considered moderate because of the limited understanding of the ecological functions of the wetlands and generally qualitative information available.

Table 4.3-7 Potential Effects and Residual Impacts for Aquatic Habitat

| Project Period | Potential Effects | Mitigation | Residual Impacts |
|----------------|--|--|--|
| construction | <p>direct displacement and loss of critical riparian, instream and ephemeral pond aquatic habitats</p> <p>effects on downstream flow and water quality during construction of water management infrastructure</p> <p>effects on aquatic and riparian habitat during water pipeline and road construction</p> | <p>local water management</p> <p>erosion control</p> <p>reduce footprint / disturbance on Torotorofotsy basin</p> | <p>high magnitude/long-term modification of local water bodies and watercourses within the mine disturbance area</p> <p>low magnitude / short-term habitat disturbance during infrastructure construction</p> <p>low magnitude /long-term loss from footprint of some facilities (water intake, bridges)</p> |
| operation | <p>continued clearing, removal and disturbance of important aquatic features associated with drainages on the ore bodies</p> <p>potential alteration of downstream watercourse habitats for aquatic biota as a result of water flow and water quality changes</p> <p>potential effects on Torotorofotsy Wetlands as a result of changes to watershed flows and water quality</p> | <p>water management plan; containment ponds</p> <p>azonal protection area</p> <p>erosion and sediment control</p> | <p>high magnitude / long-term modification of local mine area water bodies and potential low-magnitude modification of other LSA water bodies near the mine due to groundwater drawdown</p> <p>low magnitude / medium-term modification of downstream watercourses and wetlands</p> <p>long-term, positive impact from protection of ephemeral ponds and 1st order drainages in azonal protection areas</p> |
| closure | <p>changes in the landscape and development of surface water features to support productive aquatic habitat</p> | <p>water management; erosion control</p> <p>on-site reclamation /construction of riparian areas and water bodies</p> | <p>low magnitude / long-term modification of reclaimed topography and drainage system</p> |

Closure and reclamation goals will include surface water bodies (end pit lakes) or the remnants of the surface runoff containment ponds and connector streams. Depending on the success of revegetation and development of forest cover, these habitats may be suitable to support re-introduced endemic fish species. The ephemeral pond habitats, however, will be permanently lost.

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 Ephemeral Pond Mine Site 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 | low | local | medium-term | no | medium | low |
| closure | negative | low | local | long-term | no | medium | low |
| Effect: Habitat Disturbance and Water Quality Changes from Infrastructure | | | | | | | |
| construction | negative | low | local | short-term | yes | low | negligible |
| operations | negative | low | local | long-term | yes | medium | low |
| Effect: Mine Site Reclamation and Protected Areas | | | | | | | |
| operations ^(a) | positive | low | local | long-term | n/a | low | low |
| closure | positive | low | local | long-term | n/a | low | low |

^(a) Effect during operations assumed by development of protected areas; effect during closure from both reclamation activities and protected areas.

The high residual impacts to aquatic habitats in the LSA are linked to fish loss in reaches of streams that are lost to the mine footprint, even with azonal protection areas on site. This result emphasizes the need to identify off-site compensatory areas for the protection of off-site azonal forest areas and associated aquatic habitats.

Monitoring

No monitoring is proposed specifically for construction or operational effects on aquatic habitat within the immediate mine disturbance area, as these units will be totally eliminated during development of the mine. Water quality and water flow or levels will be monitored in release waters and downstream as described in Volume B, Sections 3.8 and 3.9. Post closure monitoring of flow and water quality will be continued to ensure the effectiveness and integrity of reclamation activities.

The protection and conservation measures applied to the ephemeral ponds and 1st order streams in the azonal protected areas will be monitored to ensure these areas are being preserved.

Downstream monitoring of watercourses will be based on environmental effects monitoring, which include flow and water quality integrated with periodic observations of habitat conditions.

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

4.3.6.1 Impact Pathway

The abundance and survival of aquatic biota (fish and invertebrate communities) can be affected by mine activities during construction, operation and closure phases. Changes will result from:

- community (habitat) modification and fish health;
- introduction or establishment of non-indigenous species; and
- restoration programs.

Community (Habitat) Modification and Fish Health

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 mine disturbance footprint. The alteration or disturbance of aquatic habitat in watersheds downstream of the mine (change in flows and water quality) can directly or indirectly affect the productivity and composition of fish and invertebrate communities. Disturbance of fish and invertebrate populations will also occur during watercourse crossings associated with the water pipeline, access and haul roads. Loss and disturbance of the fish and other aquatic communities using these habitats will occur during the mine project. Physical habitat assessments have been discussed in Key Question FA-1; the use of these habitats by fish species and/or macro-invertebrates will be addressed here.

Fish health effects result when the physical or chemical characteristics of water vary outside the normal tolerance range of fish. Change in fish health can result from construction and /or operation of mine production facilities and associated

infrastructure. Fish health can be affected by contaminants (from spills, effluent discharges and air emissions), changes in water quality (entrained sediments) and quantity (flows), and lethal, sub-lethal or chronic effects on fish (certain activities of construction in or near water).

Introduction or Establishment of Non-Indigenous Species

Mine or associated activities in the study area watersheds can reduce the aquatic habitat integrity and enable the spread and reproduction of exotic fish species tolerant to high turbidity, sedimentation, and other changes in degraded streams. Increased and easier access to the watersheds in the mine LSA can increase species introductions associated with human activity.

Restoration Programs

Programs will include both the restoration of aquatic habitats on the mine site to restore populations of fish and biota, and off-site species conservation management initiatives during mine operation for the long-term protection and recovery of native fish populations and other aquatic ecosystems (i.e., ephemeral pond communities).

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 various watersheds in the mine area. Within the baseline, multivariate analysis was used to assess trends in community composition. 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 B, Sections 3.7, 3.8 and 3.9); baseline contaminant data was collected from one sample of fish in the Torotorofotsy Wetlands outlet (reported in Volume B, Section 5.4 Human and Ecological Health).

Potential for exotic and non-indigenous species introductions was based on a review of mine plan information, site specific taxonomic and community structure data, and available published information.

Mine closure plans and scientific literature were used to evaluate endemic fish species recovery options.

4.3.6.3 Mitigation

Mitigations that will minimize the loss of fish species/populations and invertebrate communities from activities associated with mine construction and operation include:

Design Features

- All habitat-specific mitigation and procedures (as presented in Section 4.3.5.4) will provide some direct or indirect protection to fish communities and other aquatic biota.
- Any excess Mangoro River water transferred to the mine will be released back to the Mangoro watershed to minimize the risk of release or introduction of non-indigenous aquatic biota to other watersheds.
- Design and implementation of intake screening on the Mangoro River water pump house to prevent the entrainment of small fish and/or fish larvae and eggs.

Construction and Operation

- Implementation of a Fish Salvage Program in the key fish-bearing water streams prior to disturbance of the water body. The salvage program will include:
 - The release of salvaged endemic fish into similar / suitable natural habitats if available with consideration of desirable endemic species to the aquarium trade market (local income benefits).
 - Utilize Malagasy expertise with respect to evaluating long term conservation management techniques.
- Include protection of endemic fauna and the risk of species introductions in environmental education initiatives.
- Protection of unique aquatic ecosystems and communities (ephemeral ponds and 1st order watercourses) within the proposed Ambatovy, Analamay and offsite azonal conservation areas.

Closure

- Reclamation of surface features to create aquatic habitat in mine end pit water bodies, residual containment ponds, and connecting streams (Section 4.3.5.4).
- Re-introduction of “extirpated” endemic species from aquarium and captive breeding programs, if suitable habitats exist for their survival.

- Introduce the concept and potential for an artisan fishery, using suitable endemic species, in end pit lakes.

Compensation

- Support the Torotorofotsy Ramsar management initiative, including helping to develop fish management plans.

4.3.6.4 Results

Community (Habitat) Modification

The mine LSA contains a low number of endemic species relative to the 22 described endemic species reported for this eastern highlands ecoregion of Madagascar (Sparks and Stiassny 2003). Generally, abundance was high at undisturbed primary forest sites and low at deforested or modified locations.

Mine Disturbance Area

Within the area of mine disturbance, four of the six upper watersheds (2nd and 3rd order stream sites) exhibited community structures limited to endemic and/or native fish species. These were the Sakalava watershed, the Ankaja watershed, the Antsahalava watershed and the upper Torotorofotsy.

The project will eliminate portions of local populations of endemic *Ratsirakia*, *Rheocleis* and native species of fish (i.e., *Anguillidae*) and aquatic biota using the areas of mine site drainages within the disturbance boundary. Mitigations (i.e., fish salvage) will be implemented in an attempt to save fish where practical; however unquantifiable mortalities will occur. On site azonal conservation areas are, however, predicted to maintain their species in the mine site LSA. In addition, mitigation within azonal conservation areas at the mine will provide protection for a minimum of five ephemeral ponds to ensure preservation of the aquatic communities in these ecosystems. The inclusion of several first-order streams within these conservation areas will also afford protection to some of the additional endemic aquatic invertebrate fauna (*Probosciodopocia* – mayfly and *Madenemura* - stonefly) found in the higher altitude, pristine cool water sites.

Impacts on other non-indigenous (exotic) or native fish communities within the mine disturbance boundary will also be high; however population level impacts to these species outside the boundary of the mine disturbance are likely to be negligible because of their widespread distribution and habitat adaptability.

Downstream Drainages

The mine water management plan will mimic seasonal flow patterns. This is expected to largely maintain the current conditions for existing fish communities, and any downstream impacts related to flow alterations are considered low in magnitude. However, the loss of much of the upstream populations of *Rheocles alaotrensis* and *Ratsirakia legendrei*, could affect the long-term ability of these endemics to maintain the populations downstream of the mine area.

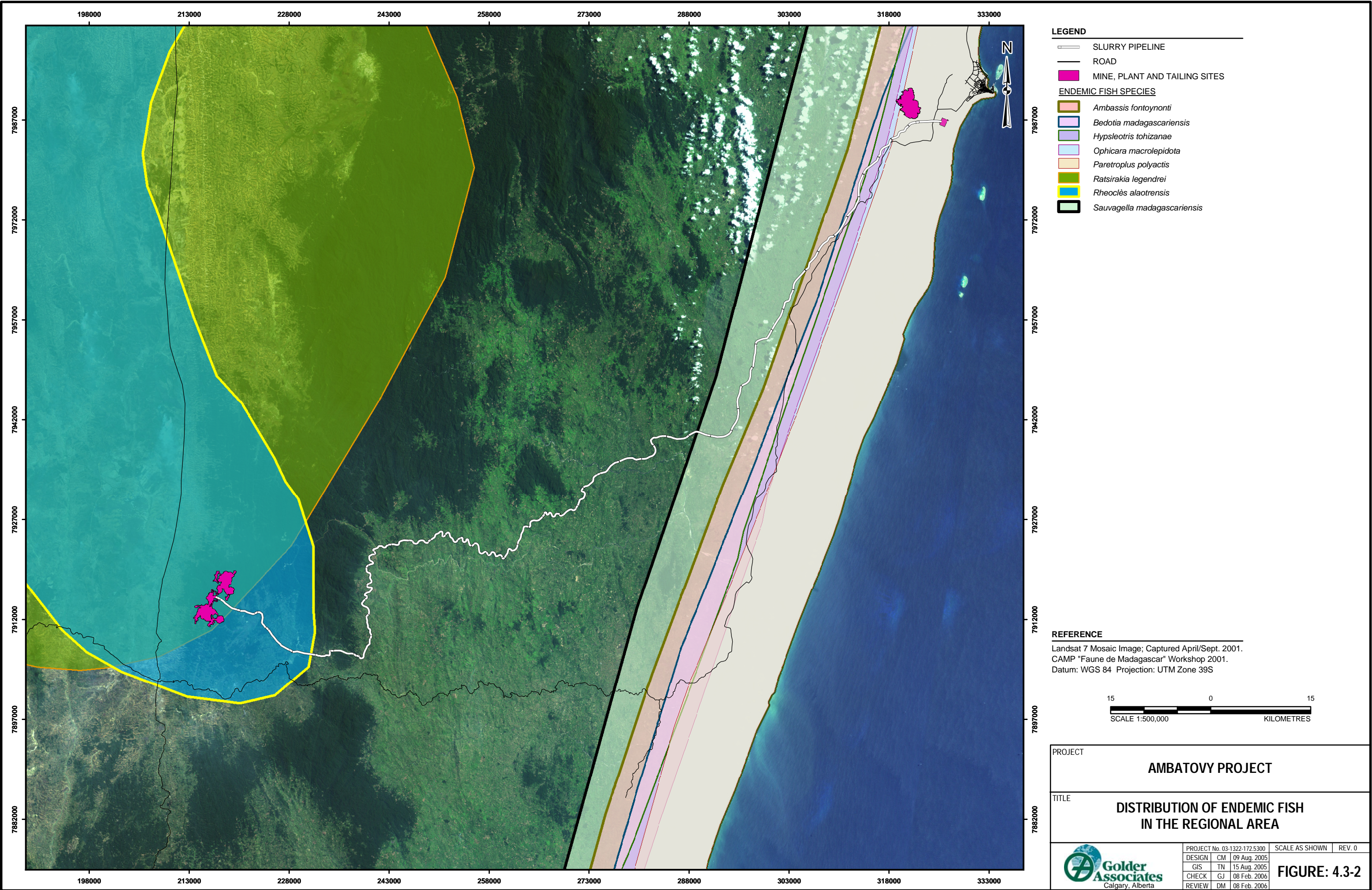
Rheocles alaotrensis and *Ratsirakia legendrei* exhibit a fairly widespread regional distribution in the upper reaches of the eastern highland drainages of Madagascar outside of the mine LSA (CAMP 2001; Figure 4.3-2). However, their extremely localized and fragmented presence (in particular for *R. alaotrensis*) in the regional watersheds, plus competition and predation by introduced species, is a significant concern for the maintenance and protection of the species (species profile; IUCN Red List of Threatened Species 2004). Depending on the regional distribution of existing endemic communities, and genetic divergence within watersheds, the project may have potential to affect the existence and diversity of these species in the LSA or regionally.

Torotorofotsy Wetlands

A small portion of the mine disturbance is located in the basin west of the Torotorofotsy wetlands and results in the loss of some headwater tributaries. However, as a result of the water management plan, surface water inflows will not be altered during the dry season, and only slight increases will occur in the wet season (1 to 3%; Hydrology assessment Volume B, Section 3.8). Water quality changes are expected to be negligible (Water Quality Assessment, Volume B, Section 3.9).

Assessment of the fish community structure and species associations (Volume J, Appendix 3.1, Attachment 1, Section 5.1.5.4) of the wetlands perimeter sites indicated that a majority of the sites contained Group II fish assemblages (i.e., dominated by exotic species, but with the original endemic fauna persisting). *R. legendrei* and *R. alaotrensis* were both generally present at these sites. The species found at one wetlands site were entirely of endemics (Group I fish assemblage), with *R. alaotrensis*, *R. legendrei* and an unidentified *Ratsiraki* species being present. However, the presence of exotic species at most wetlands sites indicates that Torotorofotsy is unlikely to provide a significant population base for endemic and native fish fauna. Drainage basin changes (flows and water quality) as a result of the mine are therefore expected to have a low impact on fish community structure in the Torotorofotsy Wetlands.

I:/2003/03-1322/03-1322-172/mxd/Fish_Aquatics/Fig4.3-2_Fish spp.mxd



Water Pipeline Route

The water pipeline could temporarily impact resident fish populations during construction and also entrain / impinge fish at the water intake location, resulting in mortalities. A majority of the fish communities within streams and rivers along the water pipeline and at the intake are exotics. Impacts to these species are likely to be insignificant because of their tolerance to habitat degradation and poor water quality.

Fish and Ecosystem Health

Fish and ecosystem health could potentially be affected by changes in water quality. The project could potentially increase the concentrations of some metals (i.e., chromium, lead and zinc) above South African Aquatic Ecosystem guideline values (Water quality assessment Volume B, Section 3.9), although some of these parameters, under baseline conditions, already exceed these criteria. These metals all display potential toxic effects on fish and / or other aquatic communities. Uptake of by the aquatic biota can occur through exposure to the water or sediments (these inorganics tend to adsorb to sediments) or food items (bioaccumulation of some metals). The key substance of concern (chromium) identified by the water quality assessment, can display a wide range of adverse effects in aquatic organisms, but toxic effects are primarily found at the lower trophic levels, such as periphyton and invertebrates (USEPA 2005). However, increased concentrations of the other metals are also of concern. Cadmium can display effects at low environmental concentrations (Eisler 1993) and freshwater fish are particularly vulnerable to cadmium exposure. Elevated levels of zinc have also been shown to cause adverse effects on survival, growth and reproduction of fish (Sorensen 1991).

Introduction or Establishment of Non-Indigenous Species

The establishment of invasive non-indigenous species is one of the most important issues confronting freshwater biodiversity (Williams and Meffe 2000) and is currently the main threat to the survival of Madagascar's freshwater endemic fish (Loiselle 2003). Over 20 exotic species have been introduced into the freshwater systems of Madagascar and have already completely replaced endemic and native fish species across most of the central highlands (Sparks and Stiassny 2003). A majority of these exotic species are tolerant of degraded habitats, poor water quality and dominate the aquatic fauna in these conditions.

Within the mine LSA, degraded habitats and exotic species are presently common in the lower portion of the watersheds, and also the upper portion of some (i.e., Sahamarirana River) within the mine boundary. Fish communities in the downstream Sahaviara River near the pipeline route consisted of five introduced species (dominated by *Tilapia zilli* and *Gambusia holbrooki*) and one

native species. Based on present land use patterns, it is likely only a matter of time until some of these species spread further upstream. A majority of the upper watersheds will be vulnerable to invasion by exotic species by creation of stressed or degraded habitats (i.e., increased turbidity, sedimentation and physical habitat alterations) as a result of project activities in the watershed. If isolated, undisturbed, portions of the drainages remain, these areas may support endemic species, but only temporarily, as without basin-wide protection, the remaining habitat is likely too small to maintain viable populations.

A potentially high impact may be the introduction of certain invasive species from the Mangoro drainage via the pipeline, affecting both the biological and genetic diversity of aquatic fauna in the mine area or specific east slope downstream drainages such as the Torotorofotsy. One particular species observed in the Mangoro drainage, the snakehead (*Channa maculata*, blotched snakehead), is rapidly spreading across Madagascar and has had a major impact on native fish populations (Benstead et al. 2003). This fish was introduced to Madagascar in about 1978; one group was stocked into ponds at Antananarivo, adjacent to the headwaters of the Betsiboka River; another group was stocked into ponds near Vatmondry on the east coast. Subsequent floods from cyclones washed snakeheads out of the ponds and into adjacent natural waters (Coutenay and Williams 2004). During surveys for this project, *C. maculata* was encountered in the Mangoro and lower Sahaviara Rivers. It has not yet been encountered in most of the middle or upper drainages of the eastern drainages off the mine area, including Torotorofotsy. Mitigation (suitable intake screening) and isolation of pumped water storage from the Mangoro will be carefully employed to reduce the potential of this species and other non-indigenous aquatic fauna into the headwaters or other east slope drainages of the mine site.

Exotic fish species have already invaded the Torotorofotsy Wetlands, presumably via the Firikana River or by deliberate introductions. During the present survey, four exotic species were found in the wetland, including *Tilapia zilli*, a larger-bodied exotic often introduced for domestic food purposes. The direct extent of downstream effects from the mine is unlikely to change or modify habitats sufficiently to affect the presence or status of these exotics. Control is difficult and invasion by these species will continue throughout the wetlands. However, it may be possible to implement some type of physical barrier on the Firikana River system to prevent upstream movements and future invasion of the wetlands by other exotic fish such as the snakehead.

Human introduction of exotic fish species (for local fish farming and consumption) is likely to occur within the LSA as a result of improved access to water bodies (such as the Torotorofotsy Wetlands) and increased local populations in response to the development. Long-term negative impacts will

occur relative to the existing remaining endemic fauna, but the effect on other existing communities (combined endemic, native and introduced fauna) is expected to be negligible, unless introductions of large predators such as the snakehead occur.

Restoration

At closure, the creation of suitable and protected aquatic habitats on the mine site may enable restoration of populations of endangered or previously extirpated endemic fish species (recovery programs). Potential may also exist on-site for commercially managed water bodies (development of fisheries/invertebrate resources for consumption and /or the ornamental fish trade).

Mine closure plans currently allow for the development of lake habitats. However, creation of watershed drainage connections would be required to restore lotic communities (the communities that live in rapidly flowing water). The impact of restoration would be positive, although the viability is unknown and the extent of effect would likely be local and low in magnitude.

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 Ambatovy Project construction operation and closure are summarized in Table 4.3-9.

The status of fish species in the mine 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 mine disturbance boundary is high, as there is very limited potential for preservation. The prediction confidence for impact ratings for fish and aquatic communities downstream, in particular the Torotorofotsy Wetlands, is moderate because of the limited understanding of the ecological functions of the wetlands.

Closure and reclamation goals will include species recovery and reintroduction into surface water bodies (end pit lakes), the remnants of the surface runoff containment ponds, connector streams, or other re-habilitated environments. The success of these initiatives cannot be accurately predicted.

**Table 4.3-9 Potential Effects and Residual Impacts for Aquatic Species
Abundance and Survival**

| Project Period | Potential Effects | Mitigation | Residual Impacts |
|----------------|--|--|---|
| construction | <p>direct mortality and eradication of important endemic aquatic species</p> <p>effects on downstream flow and water quality during construction of water management infrastructure</p> <p>effects on aquatic and riparian habitat during water pipeline and road construction</p> | <p>local water management</p> <p>erosion control</p> <p>reduce disturbance on Torotorofotsy basin</p> | <p>high magnitude/long-term modification of fish and aquatic fauna within the mine disturbance area</p> <p>low magnitude / short-term habitat disturbance of communities during infrastructure construction</p> |
| operation | <p>continued loss of aquatic biota associated with drainages on the ore bodies</p> <p>potential change to downstream aquatic biota as a result of water flow and water quality changes</p> <p>reduced viability of maintaining endemic fish populations in the LSA and regionally</p> <p>potential effects on Torotorofotsy Wetlands biota as a result of changes to watershed flows and water quality</p> | <p>water management plan ; containment ponds</p> <p>azonal protection area</p> <p>erosion and sediment system design</p> <p>water intake fish screening</p> <p>off-site conservation and preservation initiatives and research</p> | <p>high magnitude / long-term effect on aquatic ecosystems within the local mine disturbance area</p> <p>low magnitude / medium-term effect on downstream communities due to water flow and quality change</p> <p>medium magnitude / long-term effect on specific endemic fish species in the LSA and region</p> <p>low impact on existing fish and aquatic communities in the Torotorofotsy Wetlands</p> |
| closure | <p>changes in the landscape and development of surface water features to support productive endemic fish populations</p> <p>development of associated local industry (i.e., aquarium trade, etc.)</p> | <p>on-site reclamation /construction of riparian areas and water bodies</p> <p>re-introduction of local or other endemic species</p> <p>potential control (barriers) to dispersion of exotic fish</p> | <p>low magnitude / long-term population and endemic species recovery</p> <p>low magnitude /long-term social benefits</p> |

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**

| Phase | Direction | Magnitude | Geographic Extent | Duration | Reversibility | Frequency | Environmental Consequence |
|---|-----------|-----------|-------------------|------------|---------------|-----------|---------------------------|
| Effect: Habitat Modification | | | | | | | |
| construction | negative | high | local | long-term | no | medium | high |
| operations mine / region | negative | medium | local | long-term | no | medium | moderate |
| operations downstream | negative | low | local | long-term | no | medium | low |
| operations Torotorofotsy | negative | low | local | long-term | no | medium | low |
| Effect: Change to Fish and Ecosystem Health | | | | | | | |
| construction | negative | low | local | short-term | yes | low | negligible |
| operations | negative | medium | local | long-term | yes | medium | moderate |
| Effect: Establishment of Exotic Species | | | | | | | |
| operations | negative | low | local | long-term | no | medium | moderate |
| closure | negative | low | local | long-term | no | medium | moderate |
| 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, i.e., captive breeding programs.

n/a Criteria not ranked for positive impacts.

As noted for the previous key question, the high residual impacts after mitigation confirm the need for additional off-site conservation activities.

Monitoring

- Additional surveys in the mine footprint area to help focus species salvage efforts prior to construction; for fish in streams and invertebrates in ephemeral ponds.
- Water flow and quality monitoring will be implemented downstream to ensure protection of downstream habitats.
- Monitor to ensure that conservation measures to preserve the ephemeral ponds are working successfully in both on-site and off-site conservation areas.

- Routine maintenance and inspection of the water intake screen to ensure proper operation and integrity to minimize entrainment.
- Closure monitoring of species restoration and recovery programs.

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

4.3.7.1 Impact Pathway Evaluation

The harvest of aquatic biota (fish and invertebrate communities) by artisanal fisheries can be affected by mine activities during construction, operation and closure phases. Changes may result from:

- accessibility to the mine area;
- fish availability and health; and
- species changes.

Accessibility

Increased harvest of fish and invertebrates by artisanal fisheries (consumption and collection, i.e., aquarium trade) could occur because of changes in access to the mine area.

Fish Availability and Health

Mine operation could interfere with or eliminate fish populations being currently harvested in the LSA. Changes to fish health and condition could occur due to mine effects within the mine downstream drainages and infrastructure (i.e., water pipeline and service roads). This is a valid impact pathway if suitable species or populations exist or remain in the local area watersheds for harvest.

Species Changes

Species may change as a result of introductions or habitat degradation during operations. Species changes may also occur during closure and reclamation.

4.3.7.2 Assessment Methods

Mine plan information was reviewed to evaluate access and changes related to infrastructure.

Fish or invertebrate species harvest in artisanal fisheries was determined from baseline observations, projected by professional judgment from the species composition observed, or from published reports and communications.

Fish health was judged by interpretation of predicted water quality and quantity data; baseline contaminant data was collected from one sample of fish in the Torotorofotsy Wetlands outlet (reported in Volume B, Section 5.4, Human and Ecological Health).

4.3.7.3 Mitigation

Construction and Operation

- Mine site boundary closures to limit accessibility or exploitation of rare endemic populations targeted for protection.

Closure

- Development of fish /invertebrate resources for the ornamental fish trade.
- Development of an artisanal fishery, using suitable endemic species, in end pit lakes.

4.3.7.4 Results

Development of the mine road has created additional local access to the area; construction of additional haul roads, the water pipeline and service roads will enable better access to all watercourses crossed by these facilities. However, based on the fish species community assemblage encountered in the immediate mine disturbance area, and the lack of observed foraging activities for fish during the field investigations, access is expected to result in a negligible change to artisanal harvest in the mine area but possibly an increase in larger downstream water bodies (road and water pipeline) which contain a greater diversity and size of fish.

As discussed above, mitigations related to sediment input, air emissions, surface water flow and water quality will limit these changes to accepted standards. Therefore the effects on fish health and condition are considered low after mitigation, with a low environmental consequence.

Fish or invertebrate species may change as a result of accidental or deliberate introductions; or due to habitat degradation caused by project related activities. The impacts on local artisanal fisheries are difficult to assess, but unless large

populations of predators such as the snakehead become well established, the effect may be neutral as many of the fish currently harvested are exotics (i.e., *Tilapia* sp. on the Mangoro River). New species (endemics) may be introduced to the mine reclamation area during closure, and this may result in development of artisanal fisheries for consumption or aquarium trade, with a long-term positive consequence.

4.3.7.5 Impact Analysis

Residual Impacts

Residual impacts of changes to the artisanal fisheries as a result of the Ambatovy Project mine site construction operation and closure are summarized in Table 4.3-11.

Table 4.3-11 Potential Effects and Residual Impacts for Artisanal Fisheries

| Project Period | Potential Effects | Mitigation | Residual Impacts |
|----------------|--|--|---|
| construction | <p>eradication of important fish species during mining</p> <p>effects on aquatic species during water pipeline and road construction</p> | <p>fish salvage; availability for local use or sale</p> | <p>low magnitude/long-term loss within the mine disturbance area</p> <p>low magnitude / short-term loss during infrastructure construction</p> |
| operation | <p>loss of aquatic biota associated with drainages on the ore bodies</p> <p>potential change in use of downstream aquatic biota as a result of increased access</p> <p>introduction / expansion of exotic fish species</p> | <p>salvage program</p> <p>local environmental education programs</p> | <p>low magnitude / long-term</p> <p>low magnitude / medium-term change as a result of harvest of downstream fish and biota</p> <p>neutral effect on existing local harvest as a result of exotic fish introductions</p> |
| closure | <p>development of surface water features to support productive endemic fish populations</p> | <p>introduction of valued endemic species</p> | <p>low magnitude / long-term harvest of aquatic biota</p> |

The extent and use of aquatic resources within the mine disturbance area is moderately well understood and based on observation during field programs, but the level of information on specific use and harvest of aquatic resources in the downstream and remaining LSA is poorly understood. The prediction confidence for impact ratings for biota within the mine disturbance boundary is moderate, as there is limited potential for local use of the resource. The prediction confidence for impact ratings for use of fish and aquatic communities downstream is considered low.

Closure goals will include introduction of fish into surface water bodies (end pit lakes), or other re-habilitated environments. A food or ornamental fish industry may be possible; however the success of these initiatives is unknown.

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: Access Change | | | | | | | |
| construction | negative | low | local | long-term | yes | long | low |
| operations | negative | low | local | long-term | yes | medium | low |
| Effect: Changes in Fish Availability or Health | | | | | | | |
| construction | negative | low | local | long-term | no | short | low |
| operations | negative | low | local | medium-term | no | medium | low |
| closure | positive | n/a | n/a | n/a | n/a | n/a | n/a |
| 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 rated for positive impacts.

Monitoring

Closure monitoring of species re-introduction and effectiveness will be conducted to assess the development and success of artisanal fisheries.

4.3.8 Conclusions

Even with on-site conservation areas that include aquatic habitat, high environmental consequences for rare local aquatic habitat and endemic species will occur due to residual impacts from construction and operation of the mine. This finding emphasizes the need for the establishment of off-site compensatory sites.

Introduction or expansion of exotic species and their impact on remaining endemic fish species or populations as a result of activities associated with the project may also have a moderate environmental consequence. Even after mitigation, the project will likely facilitate the expansion of exotics; however in the long-term their current presence in study area water bodies and existing land use practices may result in the eradication of the endemics without the presence of the mine.

Downstream impacts on aquatic habitat and species, including the Torotorofotsy Wetlands, are expected to be largely mitigated and of low consequence. The effects on artisanal harvest of fish is also expected to be of low consequence.

Positive, but limited effects will occur because of on-site conservation of a few sensitive ephemeral ponds and a small amount of watercourse habitat being included in the protected areas.

Positive impacts, currently of unknown consequence, will be associated with the conservation of ponds and other aquatic habitats within the proposed off-site azonal habitat conservation area.

Upon closure, positive impacts may occur from aquatic habitat restoration and development or re-establishment of endemic aquatic and fish species, and potential artisanal fisheries.

4.4 NATURAL HABITATS AND BIODIVERSITY

4.4.1 Introduction

This section of the Environmental Assessment (EA) provides an evaluation of potential effects of the proposed Ambatovy Project (the project) on natural habitats and biodiversity in the mine site study area. The assessment is intrinsically linked to the flora, wildlife and fish components. In compliance with the Terms of Reference (Volume H, Section 1), site-specific data were collected to address the following elements of natural habitats and biodiversity:

- describe the current level of disturbance and biodiversity of each natural terrestrial and aquatic community type within the study area;
- describe each community type's sensitivity to disturbance and ability to be restored;
- determine the status (distribution and abundance) of each community type;
- describe landscape characteristics of the study area such as habitat connectivity and fragmentation;
- discuss the mitigation and compensatory mechanisms to be used to reduce/offset losses to natural community types;
- discuss if the project has the potential to enhance biodiversity;
- assess residual impacts for both the operations and post-closure phases of the project to natural community types and biodiversity; and
- provide details on natural habitat and biodiversity monitoring and management that include participation of local residents.

This section of the EA presents the following information:

- description of the study area used to collect baseline data and evaluate project-related impacts on natural habitats and biodiversity;
- summary of the baseline data collected and current conditions. The summary focuses on information that is most pertinent to assessing predicted impacts. A complete description of the baseline methods, analysis, and results is located in Volume J (Appendix 4.1);
- assessment of project-related impacts on natural habitats and biodiversity, including issue scoping, assessment methods, mitigations, predicted residual impacts, and an outline of proposed monitoring activities; and

- summary of conclusions regarding predicted residual impacts, and associated mitigations and follow-up monitoring activities.

4.4.2 Study Area

The core area of the mine site Local Study Area (LSA) for terrestrial resources encompasses the ore body complex (Ambatovy and Analamay ore bodies), and portions of the Torotorofotsy Wetlands that border the plateau and the associated watersheds (Volume A; Figure 7.2-1). The LSA also includes the proposed water intake pipeline footprint, plus a 500 m buffer, extending 23 km west from the core area to the Mangoro River.

4.4.3 Baseline Summary

The following provides a summary of the results of current biodiversity potential, and landscape metrics for natural habitats and land use practices in the 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 is located in Volume J (Appendix 4.1).

4.4.3.1 Ecosystem Diversity

A total of 975 species of plants, wildlife, and fish have thus far been identified in the mine study area (Table 4.4-1). Of that total, 343 species are endemic to the island of Madagascar. Forty-two percent of the plant species collected have been identified to date. Wildlife species included ants, butterflies (and moths), amphibians, reptiles, birds, bats, small mammals and lemurs. Forty-three species of wildlife, two fish species and nine plant species have International Union for the Conservation of the Nature (IUCN) status.

Table 4.4-1 Species Richness, Endemism and Conservation Status of Flora, Wildlife and Fish in the Mine Local Study Area

| | | Species Richness | Number of Endemics | IUCN Species | CITES ^(a) Species |
|-------|-------------------------|------------------|--------------------|--------------|------------------------------|
| fauna | birds | 113 | 63 | 15 | 16 |
| | reptiles and amphibians | 111 | 110 | 16 | 21 |
| | lemurs | 7 | 9 | 7 | 9 |
| | small mammals | 18 | not determined | 2 | 0 |
| | bats | 12 | 6 | 1 | 0 |
| | butterflies | 131 | about 45 to 50% | 1 | 0 |
| | ants | 75 | not determined | 1 | 0 |
| | total | 469 | 214 | 43 | 46 |
| flora | | 494 | 127 | 9 | 58 |
| fish | | 12 | 2 | 2 | 0 |

^(a) CITES = Convention on International Trade in Endangered Species of Wild Flora and Fauna.

Based on the proportional area of the LSA, the azonal, transitional and marsh ecotypes were extremely rare relative to zonal habitat (Volume J, Appendix 4.1, Section 6.1.2). Similarly, endemism of these rare vegetation communities was also high, especially for the azonal and transitional habitats which will be impacted by the mine. The marsh ecotype (i.e., Torotorofotsy) will not be impacted by the mine footprint or slurry pipeline. In contrast, zonal habitat is found elsewhere on Madagascar, and consequently has a lower intrinsic level of endemism. Overall, the cumulative ranking of natural habitats was highest for azonal and transitional ecotypes, followed by marsh and zonal ecotypes.

The number of endemic flora species was highest in the Ambatovy site, followed by Analamay and the Torotorofotsy Wetlands complex (Volume J, Appendix 4.1; Section 6.1.3.2). The number of Priority 2 (endemic to the LSA) and 3 (endemic to Madagascar) species was similar for the two ore bodies, and the number of Priority 1 species (potentially endemic to the project footprint) was 2.5 times greater in the Ambatovy site. The low number of endemics in the Torotorofotsy was likely correlated with lower sampling intensity in this area relative to the mine footprint area.

For fauna, one ant species was designated as Priority 1 in the Ambatovy site, and two amphibian species were classified as Priority 1 endemics in the Analamay site. No fauna species listed as Priority 1 in the Torotorofotsy Wetlands complex. The number of Priority 2 designated species was largely comprised of amphibians and reptiles in the Ambatovy (84%) and Analamay sites (73%),

while ants (32%) and reptiles and amphibians (54%) comprised the vast majority of Priority 2 species in the Torotorofotsy.

The two endemic fish species were abundant in the most pristine forest ecotypes, while the exotics were more abundant in disturbed areas. Some original endemic fauna persisted in moderately deforested areas, but none were detected in heavily disturbed areas (i.e., 100% composed of exotics). No fish were recorded in ephemeral pools (Volume J, Appendix 3.1).

The overall ranking score for biodiversity potential ranged from 185 for the marsh ecotype to 894 for azonal forest (Volume J, Appendix 4.1, Section 6.1.3). Azonal habitat scored the highest for most ecosystem metrics, particularly species richness, uniqueness and endemism, and habitat rarity and endemism. Transitional and zonal ecotypes had similar scores for species metrics, but habitat values were higher for the transitional habitat. The combined marsh/marsh edge forest (marsh) ecotype scored consistently lower than the other habitats for all ecosystem metrics, except habitat endemism. However, sampling intensity for flora and fauna was considerably lower in the marsh ecotype, and may be related to the relatively lower number of species recorded. Thus, in the marsh ecotype, lower sampling effort could have resulted in a negative bias in species ecosystem metrics and the associated biodiversity potential relative to forested ecotypes.

4.4.3.2 Landscape Diversity

Natural habitats consisted of six primary original ecotypes within the mine LSA, while land use classes include patches of currently disturbed forested and non-forested areas. However, very little of the habitats within the LSA have not been degraded by some form of human or natural perturbation as 89% of the landscape is currently disturbed. Results of the fragmentation analysis of the primary land cover types are provided in Table 4.4-2. The following summarizes the results according to biodiversity potential:

- Azonal habitat (including Azonal Forest and thickets) represents a small part of the LSA but has the highest biodiversity potential. The current amount of edge associated with this ecotype is relatively low compared to other ecotypes.
- Transitional forest also has high biodiversity potential and is poorly represented in the LSA.
- Zonal forest represents the largest contiguous portion of the landscape in the LSA. Because of the large area, the amount of edge associated with zonal forest is the highest among all land cover types.

- Combined marsh edge forest and marsh ecotypes comprise 5% of the LSA; all of these ecotypes are extremely rare relative to zonal habitat.
- Ephemeral pools, which are unique to the azonal forest, represent the rarest ecotype in the mine LSA. In the 1997 Phelps Dodge (PDM) study, patches of marsh edge forest and ephemeral pools were anticipated to be highly vulnerable to impacts because of their small size and patchy distribution.
- Current land use areas are associated with low biodiversity potential. The amount of edge associated with land use areas is also high.

Table 4.4-2 Fragmentation Results for Primary Vegetation Communities (Ecotypes) and Land Use Areas in the Mine Local Study Area

| Landscape Metric | Azonal Habitat | Transitional Forest | Zonal Forest | Ephemeral Pools | Marsh Edge Forest | Marsh | Other ^(a) |
|---|----------------|---------------------|--------------|-----------------|-------------------|-------|----------------------|
| total area (ha) | 1,380 | 1,489 | 12,573 | 5 | 231 | 915 | 6,301 |
| proportion of total area (%) | 6.0 | 6.5 | 54.9 | 0.02 | 1.0 | 4.0 | 27.5 |
| mean area of patch (ha) | 460 | 372 | 349 | 0.2 | 14 | 229 | 37 |
| number of patches | 3 | 4 | 36 | 30 | 16 | 4 | 171 |
| mean distance to nearest neighbour (m) | 607 | 343 | 96 | 182 | 336 | 233 | 120 |
| coefficient of variation in distance to nearest neighbour (%) | 123 | 99 | 105 | 124 | 176 | 89 | 124 |
| total edge (km) | 70 | 127 | 665 | 6 | 58 | 114 | 580 |

^(a) Includes pasture, rice paddies, eucalyptus woodlots, slash and burn areas, and villages.

Forested land classes included disturbed and non-disturbed natural treed habitats, and eucalyptus woodlots. Non-forested classes included disturbed natural habitats in early succession, and various agriculture land use patches. Wetlands, rice paddies, and human settlements were excluded from this analysis. Fragmentation analysis indicated that forested land classes covered 15,887 ha of terrestrial habitat in the LSA, while the amount of non-forested area was 5,539 ha. Mean patch size of forested habitat was 241 ha, and patches were highly dispersed on the landscape (Coefficient of variation in distance to nearest neighbour [CVDNN] = 297%). Non-forested patches were numerous and moderately dispersed throughout the landscape (number of patches = 205, CVDNN = 153%) (see Volume J, Appendix 4.1 for further discussion regarding CVDNN).

4.4.4 Impact Assessment

4.4.4.1 Issue Scoping

A principal aspect in identifying environmental issues associated with the Ambatovy project involved public consultations. Public consultations solicited input from local communities, conservation organizations and government agencies at all levels for the integration of project development. The following issues related to project-related impacts on natural habitats and biodiversity were based on public consultation and the Terms of Reference (Volume A, Section 6):

- changes to rare or sensitive natural habitats, such as the azonal forest and marsh edge forest;
- changes in species diversity;
- further fragmentation of forests west of the Mantadia-Zahamena forest corridor and Torotorofotsy Ramsar site;
- induction of indirect impacts to the Mantadia-Zahamena forest corridor and Torotorofotsy Wetlands, associated with in-migration of people; and
- positive effects related to opportunities to contribute to the conservation of the Mantadia-Zahamena corridor through targeted off-site mitigation activities and on-site restoration.

Project-related activities that are anticipated to result in changes to natural habitats and biodiversity include construction and operation of the Ambatovy mine, and reclamation during operation and closure. Specific details of the project are described in Volume B, Section 2.0. Briefly, primary activities and facilities associated with the mine that will influence natural habitats and biodiversity include:

- facility construction and operation (e.g., new mine infrastructure, the ore preparation plant and slurry transfer pumping station);
- construction and operation of open-pit mining excavations of the Ambatovy and Analamay ore bodies and hauling of low-grade material or waste to stockpile locations;
- construction and operation of intake station at the Mangoro River and water intake pipeline corridor to mine footprint (23 km length);
- construction and operation of the slurry pipeline within the mine LSA. Ore will be slurried at the ore preparation plant located between the two ore bodies and will be pumped from the ore preparation plant to the process plant located in the Toamasina area;

- construction and operation of roads; and
- reclamation during operation and closure (e.g., facilities decommissioned and removed, establishment of self-sufficient vegetative ground cover, forest reclamation).

Throughout the EA, key questions were used to develop cause and effect pathways, or a linkage diagram (Volume A; Section 7). The linkage diagram illustrating the pathways between project activities and effects on natural habitats and biodiversity are shown in Volume H, Appendix 9. These project activities also influence plant and animal populations which represent components of biodiversity. Thus, changes to flora and fauna (including fish), and habitat were assessed by asking one key question:

Key Question HB-1 What Impact Will the Ambatovy Project Have on Natural Habitats and Biodiversity?

Only linkages that have that potential to directly affect natural habitats and biodiversity, as measured by ecosystem types and landscape metrics (Volume B, Section 4.4.3), are evaluated and assessed. Indirect effects on biodiversity components such as flora, fauna, fish and aquatic resources are addressed in Volume B, Sections 4.1, 4.2, and 4.3. A summary of these anticipated effects and the location of the impact analysis in other sections of the EA is provided in Table 4.4-3.

4.4.4.2 Impact Evaluation

The indicators used to rank the biodiversity potential of primary ecotypes (habitats) in the LSA included habitat rarity, habitat endemism, species richness, species endemism, and species conservation status (IUCN and CITES) for plants, wildlife and fish (Volume B, Section 4.4.3). Direct impacts of the project on habitat and biodiversity indicators will be assessed through changes in the area, composition, and spatial configuration of habitats on the landscape (i.e., landscape metrics; Volume B, Section 4.4.3).

Table 4.4-3 Location of Biodiversity Impact Analysis Information

| Project Activities | Issue | Potential Impacts to Natural Habitats and Biodiversity | Biodiversity EA Section | Flora EA Section | Fauna EA Section | Aquatics EA Section | Health EA Section |
|-----------------------------------|---|--|-------------------------|------------------|------------------|---------------------|-------------------|
| Construction and Operation | | | | | | | |
| site clearing and infrastructure | loss and fragmentation of vegetation and wildlife and aquatic habitat | loss of plant, fauna and fish species | Y | Y | Y | Y | |
| | | loss of endemic and listed plants, fauna, and fish | Y | Y | Y | Y | |
| | | change in landscape composition | Y | | | | |
| | | change in landscape configuration | Y | | | | |
| | | direct wildlife mortality | | | Y | Y | |
| | | barriers to wildlife and fish movement | | | Y | Y | |
| | | barriers to dispersal | | Y | Y | Y | |
| | | sensory disturbance to wildlife and fish | | | Y | Y | |
| | | | | | | | |
| | change in access | change in hunting, trapping and fishing, and predation | | | Y | Y | |
| | | increased vehicle-wildlife collisions | | | Y | | |
| | change in air quality | change in plant and animal tissue quality | | Y | Y | Y | Y |
| | change in hydrology | change in terrestrial and aquatic habitats | | Y | Y | Y | |
| | change in water quality | change in plant and animal tissue quality | | Y | Y | Y | Y |
| Operation and Closure | | | | | | | |
| reclamation | replacement of habitat | change in all above potential impacts | Y | Y | Y | Y | |

Note: Y = yes.

Potential Impact Pathways

Development of the project will result in the loss or alteration of approximately 1,849 ha of habitat in the LSA (including associated buffers and the road and pipeline corridors leading to the mine). Of all possible sources of impacts from project construction and operation, habitat loss is among the most important as it reduces the landscape's capacity to support plant, wildlife and fish species (Fahrig 1997; Andr  n 1999; Fahrig 2003). Since the theory of island biogeography was introduced by MacArthur and Wilson (1967), many studies have demonstrated the negative relationship between habitat area and species richness and abundance (see review by Debinski and Holt 2000). Many of the species are also endemic and/or have special conservation status (Volume B, Section 4.4.3).

The removal and alteration of habitat during construction and operation also results in the fragmentation (or breaking apart) of ecotypes on the landscape. Key changes associated with fragmentation include mean patch size, number of patches, habitat connectivity (mean and coefficient of variation of distance to nearest neighbour), and amount of edge (Fahrig 2003). The amount of rare and endemic habitats will be influenced by changes in mean patch size and number of patches. However, connectivity and edge effects do not affect the amount of rare or endemic habitats.

The greatest impact of fragmentation will be on the biota that inhabits the landscape within the LSA, particularly the azonal and transitional habitat types characteristic of the Analamy and Ambatovy ore bodies which are located adjacent to the Mantadia-Zahamena corridor. The process of fragmentation often results in disconnected habitat fragments with a high proportion of open perimeters. Subsequently, fragmentation can increase the amount of habitat edge, decrease the amount of habitat interior, and increase the distance between habitat patches (Turner 1996; Fahrig 1997, 2003).

Forest edge and interior changes can negatively influence species within habitats by changing moisture, light and nutrient regimes (Kitchell et al. 1979; Kapos 1989; Saunders et al. 1991; Brown 1993; Nichol 1994). Such changes in microclimate are particularly important for some species of plants, fish, amphibians, and reptiles. It also increases the chances of introduction (accidental or otherwise) of invasive or exotic species which can out-compete and replace unique niches once held by native species within an ecosystem (Turner 1996; Debinski and Holt 2000; Benstead et al. 2003). Mitigations for control of weeds and invasive species should limit these effects (see Mitigation). Edges can also alter population and community dynamics, and the composition of indigenous species (Karieva 1987; Fagan et al. 1999).

Increased spatial separation of habitats can impact the movement, dispersal (animals and plants), survival, and reproduction of individuals which may change the probability of persistence of populations (Turner 1996; Fahrig and Paloheimo 1988; Pulliam 1988; Hanski 1996; Debinski and Holt 2000).

Reclamation during operation and closure is often the first step in re-establishing a natural ecosystem. During closure, successful reclamation could reverse some of the effects of the project on natural habitats and biodiversity.

Table 4.4-4 summarizes the evaluation of potential impact pathways for natural habitats and biodiversity.

Table 4.4-4 Summary of Impact Pathways to Natural Habitats and Biodiversity

| Natural Habitat and Biodiversity Metrics | Potential Impact Pathways | | | | | |
|--|---------------------------|-----------------|-------------------|----------------------|--------------|-------------|
| | Habitat Area | Mean Patch Size | Number of Patches | Habitat Connectivity | Edge Effects | Reclamation |
| habitat rarity (area) | Y | Y | Y | N | N | Y |
| habitat endemism | Y | Y | Y | N | N | Y |
| species richness | Y | Y | Y | Y | Y | Y |
| species endemism | Y | Y | Y | Y | Y | Y |
| species conservation status | Y | Y | Y | Y | Y | Y |

Note:

Y = Yes;

N = No

Assessment Methods

Baseline data for habitat rarity and endemism, and species richness, endemism and conservation status (IUCN and CITES listings) for plants and wildlife were used to estimate the current biodiversity potential of primary ecotypes within the LSA (Volume B, Section 4.4.3). Information on species richness, endemism, and conservation status of fish was also obtained to assess the relative contribution of aquatic macrofauna to biodiversity in the LSA. There is a strong link among patterns of biodiversity, population persistence and landscape attributes (or metrics) such as habitat area, patch size, spatial dispersion of patches, connectivity and edge (Brown 1995; Debinski and Holt 2000; Fahrig 2003). Therefore, fragmentation analysis of the LSA under baseline conditions was completed to quantify the current area, composition and spatial configuration of habitats (Volume B, Section 4.4.3).

Direct impacts from the project on habitat and biodiversity indicators were assessed through changes in the area, composition, and spatial configuration of habitats on the landscape. To estimate the change in landscape area associated with the project, fragmentation analysis was done on the LSA after applying the mine footprint to the landscape (application case). The footprint included the core mine area (e.g., site facilities, roads, pits, waste rock storage areas), water intake pipeline, and a portion of the slurry pipeline extending from the slurry plant to the LSA boundary. Core mine site disturbances included a 50 m buffer, and the slurry pipeline and water intake pipeline were buffered by 50 m and 25 m, respectively. Analysis was conducted using FRAGSTATS (Version 3.0) within a Geographic Information System (GIS) platform.

The potential impact of the project on biodiversity indicators was estimated by calculating the relative difference between application case and baseline landscape metrics using the following equation:

$$(\text{application case value} - \text{baseline value}) / \text{baseline value}$$

The resulting value was then multiplied by 100 to give the percent change in a landscape metric associated with the project relative to baseline conditions, and provides both direction and magnitude of the impact. For example, a high negative value for habitat area would indicate a substantial loss of that habitat. Alternately, a negative value for mean distance to nearest neighbour indicates an increase in habitat connectivity. Changes in landscape metrics were then used with assessment criteria (see below) to predict impacts from the project on biodiversity potential among ecotypes, and within the LSA. Impacts to habitats associated with human land use activities (negligible biodiversity potential) were not assessed here (see Volume B, Section 5.3 [Land Use]).

Impacts were assessed for the period of construction through operation, and the closure phase. It is assumed that maximum impacts will occur during the period of construction through operation, particularly during construction and initial stages of operation when the direct loss and alteration of azonal and transitional habitats will be greatest. Alternately, because reclamation is proposed to occur during late operation and closure, impacts could have been assessed from construction through closure, which would have decreased the expected magnitude of effects (reclamation is assumed to mitigate impacts). This approach was not taken because: (1) the intent was to assess the maximum potential impacts from the project, and (2) the duration of successful reclamation is uncertain.

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. Definitions of the residual effect classification terms that are specific to habitats and biodiversity are provided in Table 4.4-5. Determination of the overall environmental consequence uses magnitude, geographic extent, and duration, and is described in Volume A, Section 7.

Magnitude or severity of the impact is the most difficult criterion to evaluate. In a perfect world, effect threshold values would be known, and measurement endpoints could be measured accurately with a high degree of confidence. However, little is known about ecological effect thresholds, particularly in tropical systems, and biological parameters are typically associated with a large amount of natural variation. The approach used to classify magnitude was based on scientific literature, and incorporated conservatism.

Based on a risk assessment approach, Suter et al. (1995) have identified that the 20% rule for the severity of effects from contamination is applicable to varying spatial scales of ecological effects (i.e., a 20% change in a measurement endpoint constitutes an ecological effect). Other empirical and theoretical studies have examined the relationship between loss of suitable habitat and landscape type, and the likelihood of population decline (Andrén 1994; Fahrig 1997; With 1997; Mönkkönen and Reunanen 1999; Andrén 1999). These studies suggest that critical thresholds for declines in non-tropical bird and mammal species occur in between 10% and 60% of original habitat. In other words, a decrease in species abundance and diversity may be observed when the amount of suitable habitat lost exceeds a threshold value of 40% to 90%. These impacts are variable, and species are predicted to exhibit a diverse array of responses to habitat loss and fragmentation depending on specific life history traits and dispersal capabilities (With and King 1999).

Because habitat effect threshold values on population persistence in tropical systems have not been estimated, a more conservative value of 20% was used to define the maximum severity of an impact (Table 4.4-5). This value also corresponds to the effect threshold recommended by Suter et al. (1995) for identifying potential ecological risk.

Table 4.4-5 Impact Description Criteria for Natural Habitats and Biodiversity

| Direction | Magnitude | Geographic Extent | Duration | Reversibility | Frequency |
|--|---|--|---|----------------------------|---|
| neutral: no change in biodiversity indicators negative: a change in biodiversity indicators | negligible: no measurable effect on biodiversity indicators low: <10% change in biodiversity indicators moderate: 10 to 20% change in biodiversity indicators high: >20% change in biodiversity indicators | 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 |

Mitigation

Several mitigations are assumed to reduce the magnitude, geographic extent and duration of direct impacts from the project on natural habitats and biodiversity in the mine site study area. More details of these mitigations are provided in the flora, fauna and aquatic resources EA sections (Volume B, Sections 4.1, 4.2 and 4.3). Mitigation includes:

- establishing two on-site conservation areas amounting to 306 ha. One area is located in the Ambatovy site (211 ha), and includes three ephemeral pools (0.18 ha), non-disturbed azonal forest (52 ha), and disturbed azonal and transitional forest (159 ha). The other is located in the Analamay site (95 ha), and includes three ephemeral pools (0.13 ha), non-disturbed azonal and transitional forest (92 ha), and disturbed transitional forest (3 ha);
- constructing some strategic sections of fencing between mine footprint and conservation areas;
- avoiding direct (physical disturbance) and minimizing of indirect (changes in water quantity and quality) effects to the Torotorofotsy Wetlands complex;
- conducting public information / awareness sessions regarding the land use practices near rehabilitation and conservation areas;
- creating an on-site sanctuary for vulnerable plant species (transplant, cultivation/propagation, re-introduction);
- implementing weed control in newly developed areas;
- moving vulnerable fauna to safe sites such as conservation areas and off-site azonal habitat;

- conducting habitat rehabilitation work and studies using native species to support the reclamation and closure plans; and
- participating in regional resource planning with the Malagasy government.

Compensation

- participating in the development and implementation of a forest management plan to maintain biological integrity of conservation areas (Volume B, Section 7); and
- protecting similar off-site compensatory azonal habitat.

The analysis in this section focuses on defining residual impacts in the LSA after mitigation. The further benefits of applying biodiversity off-sets (compensation) are more fully included in the cumulative effects analysis (Volume G, Section 3.4).

Results

Vegetation structure and composition of primary terrestrial and wetland habitats (ecotypes) in the mine LSA are associated with specific moisture, nutrient and soil (e.g., ferricrete, pisolite, clay, peat) regimes (Volume J, Appendix 1.1). These differences in abiotic and flora attributes support different fauna species and communities (Volume J, Appendix 2.1 and 3.1), some of which may be more resilient to disturbance than others. The empirical and theoretical relationships between habitat loss and negative effects on biodiversity are well documented, however, most studies have been conducted in non-tropical environments. Habitat loss has been linked with decreases in species richness, population abundance and distribution, and genetic diversity (Lande 1987; Hanski et al. 1996; Findlay and Houlihan 1997; Gibbs 1998; Wettstein and Schmid 1999; Best et al. 2001; Gibbs 2001; Bascompte et al. 2002; Donovan and Flather 2002; Schmiegelow and Mönkkönen 2002). Habitat loss has also been shown to negatively change species interactions (e.g., predation rate, competition), and the effective dispersal, reproductive success, and foraging behaviour of individuals (see Fahrig 2003).

Habitat fragmentation can also negatively influence individual, population and community processes that are coupled with biodiversity, but fragmentation effects have less impact than habitat loss (Fahrig 1997; Andrén 1999; Fahrig 2003). Similar to habitat loss, there is a lack of studies on fragmentation effects in tropical systems. The breaking apart of habitats on the landscape changes patch size and number, connectivity between similar habitat patches, and the amount of interior and edge of remnant patches. As noted above, these

landscape scale changes have been shown to alter abiotic (moisture, nutrients) and biotic processes, such as dispersal and reproductive success, predation, parasitism and competition.

A striking result of fragmentation studies is that not all effects were negative (see reviews by Debinski and Holt 2000, and Fahrig 2003). For example, of the 17 studies reviewed by Fahrig (2003), the likelihood of positive or negative effects from fragmentation was similar.

Analysis indicates that biodiversity potential in the LSA will be most likely impacted by habitat loss and fragmentation of azonal and transitional forest, and ephemeral pools. These ecotypes are located in the Ambatovy and Analamay ore bodies which are adjacent to the Mantadia-Zahamena corridor. Baseline data showed that the azonal ecotype ranked the highest for biodiversity indicators, particularly species richness, number of endemic species, and habitat rareness and endemism (Volume B, Section 4.4.3). Transitional and zonal ecotypes were similar with respect to species indicators, but habitat values were higher for transitional habitat. The low availability, patchy distribution, and high endemism of ephemeral pools (i.e., associated with ferricrete in azonal habitat) also makes this ecotype sensitive to disturbance (Volume B, Section 4.4.3). The combined marsh edge forest and marsh ecotype, which are located in the Torotorofotsy Wetlands, also has moderate to high biodiversity potential, but will not be directly impacted by the project (Table 4.4-6).

Development of the project is expected to decrease the area of azonal habitat (including combined areas of azonal Forest and thickets) and ephemeral pools by 71% (from 1,380 to 395 ha) and 87% (from 5 to 0.6 ha), respectively (Table 4.4-6). Transitional habitat will be reduced by 23% (from 1,489 to 1,145 ha), and a 3% decrease (from 12,573 to 12,188 ha) in zonal habitat is anticipated. The decrease in area of zonal habitat should have a negligible influence on biodiversity in the LSA, however, the loss of azonal and transitional forest, and ephemeral pools will probably have a negative impact on flora and fauna populations.

A decrease in population size is associated with greater risks to population persistence due to environmental and demographic stochasticity (Gilpen and Soulé 1986; Hanski 1996). However, the lack of knowledge regarding current population size and demographic variables for flora and fauna species (i.e., survival, recruitment and effective dispersal distance) among habitat patches on the landscape generates uncertainty in predicting the magnitude of the impact on biodiversity indicators.

Table 4.4-6 Change (%) in Landscape Metrics for Full Development of the Mine Relative to Baseline Conditions for Natural Habitats and Land Use Areas in the Local Study Area

| Landscape Metric | Azonal Habitat | Transitional Forest | Zonal Forest | Ephemeral Pools | Marsh Edge Forest | Marsh | Other ^(a) |
|---|----------------|---------------------|--------------|-----------------|-------------------|-------|----------------------|
| total area | -71.4 | -23.1 | -3.1 | -87.2 | 0.0 | 0.0 | 27.2 |
| mean area of patch | -96.7 | -86.6 | -34.0 | -56.3 | 0.0 | 0.0 | 35.1 |
| number of patches | 767 | 475 | 47.2 | -73.3 | 0.0 | 0.0 | -6.4 |
| mean distance to nearest neighbour (MDNN) | -80.6 | -70.3 | -13.5 | 17.0 | 0.0 | 0.0 | -1.7 |
| coefficient of variation in distance to nearest neighbour (CVDNN) | -23.8 | -14.1 | -1.9 | -10.5 | 0.0 | 0.0 | -3.2 |
| total edge | -20.0 | -15.7 | 2.6 | -83.3 | 0.0 | 0.0 | 13.3 |

Note: Values calculated as (application case – baseline) / baseline.

^(a) Includes mine infrastructure, pasture, rice paddies, eucalyptus woodlots, slash and burn areas, and villages.

Application of the project infrastructure also resulted in fragmenting the existing habitats within the LSA. Average size of azonal patches decreased by 97% (from 460 to 15 ha) with a correspondent increase in the number of patches (from 3 to 26). Similarly, mean patch size of transitional habitat decreased 87% (from 372 to 50 ha) and the number of patches increased from four to 23 due to project development (Table 4.4-6). In contrast, the 56% decrease in average patch size (from 0.2 to 0.07 ha) of ephemeral pools was associated with a 73% decrease (from 30 to 8) in the number of pools, which was coupled with the small area of individual patches. Six of these remaining pools are located in the proposed Ambatovy and Analamay conservation areas.

Smaller patches can result in negative effects similar to those linked to habitat loss. At some point the area of patches may be too small to support a viable local population, or the distance between local populations too great for effective emigration which reduces re-colonization success and metapopulation persistence (Hanski 1996; Pulliam 1996; Turner 1996; Fahrig 2003).

Changes in population and community interactions (e.g., competition, mutualism, commensalism, parasitism and predation) may result in a loss of plant and animal species. Conversely, the loss of species can negatively alter or impair ecosystem function, stability and resilience (Lawton 1994). For example, studies near Manaus in Amazonian Brazil have demonstrated that small fragments contain fewer species of termites, beetles, frogs, understory birds, small mammals, and primates than larger or more continuous forest patches (see Turner 1996). Other studies have shown that there was a recognizable difference in the composition and species richness of a beetle community in a 100 ha patch relative to continuous forest (Laurance and Bierregaard 1996). Some amphibian species of

the family Myrohyllidae in Madagascar were detected only in forested fragments of 30 ha to 40 ha in size (Vallan 2003). However, if water is available in forest fragments, then amphibians may be more tolerant of reductions in patch size than reptiles, birds, and small mammals (Vallan 2003).

The analysis also indicated that the project slightly modified the spatial dispersion and connectivity of azonal, transitional and ephemeral pool habitats on the landscape. There was an 11% to 24% reduction in the aggregation of these habitats within the local area adjacent to the Mantadia-Zahamena corridor (Table 4.4-6). Within the LSA, these habitats became more randomly dispersed. For example, the CVDNN decreased from 123% to 93% for azonal habitat, and from 124% to 111% for ephemeral pools. MDNN for azonal habitat decreased from 607 to 118 m, and from 343 to 102 m for transitional habitat. However, the loss of ephemeral pools resulted in MDNN increasing from 182 to 213 m. Total edge for all three ecotypes decreased relative to baseline conditions (Table 4.4-6).

Fragmentation studies in tropical and non-tropical systems have suggested that breaks between forest patches of 50 m to 100 m can result in substantial barriers to movement in many species of birds and insects (Turner 1996; Debinski and Holt 2000). Because many species of birds, insects and small mammals (including bats) provide carriers for pollen and seeds, barriers to animal movement can also retard gene flow and dispersal of plant species among habitat patches. The increase in connectivity between forest fragments and decrease in total edge associated with the project may benefit some species. But again, the lack of knowledge on population status and effective dispersal distance for species limits the confidence in assessing the strength of fragmentation impacts to flora and fauna species richness, and the number of endemic and listed species.

Residual Impacts

Despite mitigation, activities related to construction, operation and closure of the mine will result in negative changes to natural habitats and biodiversity. Although baseline information determined that the mine LSA is currently 89% disturbed, there are several ecotypes that support many flora and fauna species, many of which are endemic to Madagascar and have special conservation status. These ecotypes included azonal, transitional and zonal forest, ephemeral pools (which are found only in azonal forest), and marsh edge forest and associated marsh habitat. Because the Torotorofotsy Wetlands will be avoided by the mine footprint, no impacts to marsh edge forest or marsh habitat are expected. Also, the small decrease in zonal forest (3%) associated with the project relative to the current area (12,573 ha) should have a negligible influence on the plants and animals dependent on this ecotype.

Analysis of landscape areas indicated that the fraction of natural habitat expected to be lost due to the project footprint is 71.4% (985 ha) of azonal forest, 23.1% (344 ha) of transitional forest, and 87.2% (4.4 ha) of ephemeral pools. Average patch size of these ecotypes decreased by between 56% and 97% (Table 4.4-6). The increase in patch connectivity may benefit species inhabiting azonal and transitional forest, but the decrease in connectivity between ephemeral pools will likely have a negative influence for species dependent on this ecotype. Based on the negative changes in habitat area, mean patch size and assessment criteria, the magnitude of the impact from the project on these natural habitats and associated biodiversity is predicted to be high during construction and operation (Table 4.4-7).

Table 4.4-7 Residual Impact Classification for Natural Habitats and Biodiversity

| Project Period | Direction | Magnitude | Geographic Extent | Duration | Reversibility | Frequency | Environmental Consequence |
|---|-----------|-----------|-------------------|-------------|---------------|-----------|---------------------------|
| What Impact Will the Ambatovy Project Have on Natural Habitats and Biodiversity? | | | | | | | |
| construction / operation | negative | high | local | long-term | irreversible | medium | high |
| closure | negative | moderate | local | medium-term | reversible | medium | moderate |

Direct impacts from the project on azonal and transitional ecotypes are predicted to be local in geographic extent. Impacts from construction and operations are predicted to be medium in frequency as construction of facilities and mining of ore deposits will occur in stages. The effects from the project on habitat loss, patch size, connectivity and biodiversity will extend into the closure period, and therefore will be long-term (Table 4.4-7).

Excavation of the ore-bodies will remove the ferricrete substrate which supports the azonal forest, and habitat loss of this ecotype (and associated ephemeral pools) will be irreversible (Volume B, Section 4.1). Early seral stages of zonal forest and degraded forest can be expected to establish relatively quickly on reclamation areas (Volume B, Section 4.1).

During closure, reclamation is anticipated to reverse impacts to a moderate magnitude. Revegetation will likely provide habitats with similar structure and composition as transitional and zonal forest, and provide suitable habitat for some species of endemic flora and fauna. Continuation of public awareness programs from operation through closure on the ecological benefits of conducting land use practices away from conservation and reclamation areas should help reverse impacts including in a regional forest buffer zone. In

addition, the proponent's involvement in a forest management plan for the region may increase biodiversity potential in an area that is currently 89% disturbed, and projected to be mostly deforested within the next 20 years (Green and Sussman 1990).

Changes to population and community dynamics in the LSA during construction and operation should begin to relax with a correspondent increase in stability in the ecosystem. It is important to acknowledge that habitats and the ecosystem within the LSA will likely not return to current conditions. Populations, communities, and ecosystems are constantly responding to natural and human-induced environmental perturbations, and are in a state of dynamic equilibrium (Holling 1973; Matthews et al. 1996). The post-development state of an ecosystem may be equally functional with the desired structure and composition, but it will not be the same as before development (Landis and McLaughlin 2000).

Reclamation will occur periodically (medium frequency) during closure, and establishment of suitable habitat is expected to occur within 30 years (medium-term duration). Similar to construction and operation, effects of closure activities will occur on a regional scale.

Taking all criteria into consideration, the environmental consequence of direct impacts from the project on natural habitats and biodiversity is predicted to be high during construction and operation, and moderate during closure (Table 4.4-7). This finding is directly related to the linkage between the azonal habitats and the soil of the ore bodies that are mined. The setting aside of on-site azonal conservation areas constitutes a very important mitigation commitment. However, given the high ecological consequence of impacts during construction and operation, the continued investigation of additional off-site azonal conservation areas also remains a priority (Volume B, Section 4.1).

Prediction Confidence

Like all scientific results and inference, residual impact predictions must be tempered with uncertainty associated with the data and current knowledge of the system. Here, confidence in impact predictions is related to three main elements:

- adequacy of baseline data for understanding current conditions;
- understanding of project-related impacts on the ecosystem; and
- knowledge of the effectiveness of mitigation.

Estimates of the metrics used to assess current biodiversity in the LSA (i.e., species richness, endemism and conservation status) were a function of

sampling intensity and distribution, and the types of taxa sampled. For several taxonomic groups such as plants, ants and butterflies, species accumulation curves did not asymptote, suggesting that further sampling would have generated more species. This is not surprising considering the amount of effort required to collect a detailed inventory of tropical species, even from one area (Lawton et al. 1998). In addition, sampling was restricted to the LSA which likely produced an overestimate in the number of Priority 1 and Priority 2 endemic species that may be impacted. There is a moderately good understanding of what the baseline conditions are, however, fundamentally due to the complexity of the science, there is a high degree of uncertainty in understanding the functional relationships and mechanisms that have led to the current number and distribution of species observed in the study area.

The amount of confidence in understanding impacts of the project is variable; although it is well documented that habitat loss causes negative impacts on populations and communities, the effects of impacts relating to fragmentation or indirect disturbance are less well understood. Confidence in predicting impacts therefore varies from low to moderate.

The cessation of mining activity and concurrent habitat reclamation is assumed to help reverse the negative effects of the project (i.e., stabilize the ecosystem). Early seral stages of zonal forest can be expected to establish quickly on reclamation areas. Re-establishment of transitional habitat will likely be more difficult, but a successful process will be developed through a series of site trials. The azonal habitat is, however, not expected to return to its original state. Stochastic events (e.g., fire, extreme drought or cyclones) and future human land use practices (e.g., plantations, agriculture) may limit future biodiversity potential of this area.

Monitoring

The overall objective of monitoring is to test the effectiveness of mitigation measures, and detect unanticipated effects. In particular, should problems be found with the viability of the on-site azonal conservation areas, then following through with the protection of compensatory off-site areas would be required. The monitoring program for biodiversity is composed of flora, fauna and fish components (Volume B, Sections 4.1, 4.2 and 4.3). Changes to ecosystem processes and function will focus on abiotic variables such as water quality, hydrology and air quality (dust and air emissions). Habitat loss and fragmentation metrics will also be assessed periodically (i.e., every two to three years). Permanent sample plots will be established in azonal conservation areas. Reclamation areas and habitats located at various distances from the mine footprint will be monitored for selected flora and fauna species.

4.4.5 Conclusions

Change in area, composition and spatial configuration of habitats were used to assess the direct impacts from the project on natural habitats and biodiversity. Following mitigation, analysis indicated that there should be no residual impacts to the Torotorofotsy Wetlands complex, and negligible effects to species inhabiting the zonal forest ecotype. The greatest impacts will result from disturbance to azonal habitats, transitional forest and ephemeral pools. Residual impacts during construction and operation are predicted to be of high magnitude, regional in geographic extent, and continue over the long-term. During closure, ongoing reclamation and protection of conservation areas are anticipated to reverse residual impacts (except for the loss of azonal habitat and associated ephemeral pools) to moderate magnitude. The extent of the effects will be regional and medium-term in duration. Overall, the environmental consequence of the project on natural habitats and biodiversity is predicted to be high during construction and operation, and moderate during closure.

The project will negatively impact natural habitats and associated biodiversity within the study area. However, the severity of the impact on the ecosystem is uncertain. The establishment of on-site azonal conservation areas and habitat reclamation will assist in mitigating the impacts. In addition, because of the unavoidable high residual impacts in the LSA, off-site compensation activities involving both azonal and zonal (buffer zone) habitats will take place as biodiversity off-sets. An analysis of combined project impacts on biodiversity, including positive effects of offsets, is provided in Volume G, Section 3.4. From a cumulative perspective, buffer zone forest management and other biodiversity offsets allow the project to work towards a net positive impact on biodiversity during operations and closure.

The monitoring program used to monitor flora and fauna will test the effectiveness of biodiversity mitigation, and detect unanticipated effects. The results of the monitoring will be used to determine whether changes may be needed to the applied mitigation.

4.5 PROTECTED AREAS

4.5.1 Introduction

This section presents the Environmental Assessment for the effects of the mine on existing and planned protected areas. As per the Ambatovy Project Terms of Reference, the potential impacts of the mine on the ecological integrity and economic sustainability (e.g., tourism) of protected areas within the regional study area are evaluated.

4.5.2 Study Area

For protected areas, two study areas are used: a Local Study Area (LSA) that will encompass the area likely to be directly impacted by the Ambatovy Project (the project), and a Regional Study Area (RSA) that includes the area subject to indirect effects of populations who move into the area to work at the mine.

The mine LSA for protected areas is the same as the terrestrial study area presented in Volume A, Section 7, Figure 7.2-1. It includes the mine and water intake pipeline disturbance areas, plus a 500 m buffer around those areas in all directions. The LSA also includes the Torotorofotsy Wetlands and the basin within 500 m of these wetlands. The mine RSA includes all areas within 100 km of the mine site.

4.5.3 Baseline Summary

The Torotorofotsy Ramsar Site is located partly within the mine LSA (Volume J, Section 6.1, Figure 6.1-1). Torotorofotsy is the largest and most intact natural marsh in eastern Madagascar. Ramsar sites are not protected until specific legislation is enacted by the state of Madagascar; however, Ramsar sites are wetlands of recognized international importance, which have been designated based on their significance in terms of ecology, botany, zoology, limnology or hydrology. Generally, it is expected under the Ramsar Convention that Ramsar sites will receive some kind of protected status incorporating the “wise use” concept (Ramsar Secretariat 2004). The Torotorofotsy Wetlands are presently used for ecotourism, small-scale hunting and plant harvesting, and (at the perimeter of the wetlands) rice farming, small-scale sustainable forestry (eucalyptus trees) and human habitation; 83% of the Ramsar site is within the mine LSA and has been classified as to land use. Under baseline conditions, 40% of the portion of this Ramsar site that is in the LSA has been disturbed by either slash-and-burn (tavy) agriculture, eucalyptus plantations or use as rice paddies.

The proposed Mantadia-Zahamena Conservation area¹ is also located partly within the mine LSA. The Mantadia-Zahamena Corridor does not yet have any protected status but is in the process of being defined as a type of *Site de Conservation* by the Government of Madagascar, with input from other interested parties. Tentative boundaries for the conservation area close to the mine are shown in Volume J, Section 6.1, Figure 6.1-1. An agreement has been signed between Dynatec and representatives of the Government of Madagascar (June 21, 2005), stipulating that conservation area boundaries will not overlap Dynatec's mining rights areas (Carrés Miniers). The precise boundaries and protected status of the area have yet to be established, but are expected to be finalized in 2006. The protected area is planned to accommodate area for both biodiversity protection (75%) and multiple-use areas (25%).

Other proposed or existing protected areas within the mine RSA are Mantadia National Park, Analamazaotra Special Reserve, Anjozorobe Forest Corridor and Maromiza State Forest / private protected areas.

Additional details concerning all proposed and existing protected areas in the mine LSA and RSA are provided in Volume J, Section 6.1.

In general, tourism in Madagascar, including tourism in protected areas has experienced strong growth between 1992 and 2002, and again since 2002, despite a drop in 2002 due to political reasons (PTE/EDEND 2004; Madagascar Contacts Website 2004). Ecotourism is regarded as an important growth industry at the national level.

4.5.4 Issue Scoping

Protected areas constitute both a source of tourism income and a way to preserve the natural heritage of Madagascar. Effects on these areas, both existing and proposed, must be considered and minimized wherever possible, either by choosing appropriate location and routing options or by applying effective mitigations. Public consultation recorded a concern that the project not impact protected areas, including the Torotorofotsy Ramsar site (Volume A, Section 6).

¹ In the new Arrêté 20-021, ratified on December 30, 2005, the corridor is referred to as the Akeniheny-Zahamena Corridor (CAZ). In addition, this Arrêté proposes a new set of boundaries for the temporary protection of the conservation area to be created. This information was not available while the EA was being conducted and therefore the EA reflects the state of affairs as of mid 2005.

Potential effects of the mine on protected areas may occur due to:

- direct alteration of habitat within an area due to project development;
- fragmentation of habitat within an area due to project development;
- indirect impacts in an area due to changes in water quality or quantity;
- indirect impacts within an area due to induced development, changes in land use or changes in tourism; or
- enhanced protection and management of protected lands as a result of financial support from the project.

Linkages of effects on protected areas to other components are shown in a linkage diagram (Volume H, Appendix 9).

The key question for protected areas is:

Key Question PR-1 What Effects, Direct and Indirect, Will the Mine Have on Protected Areas?

4.5.5 Impact Assessment

The mine footprint will directly affect part of the Torotorofotsy Ramsar site, including part of the watershed of the wetlands, although not the wetlands themselves. Due to the mine's location at the west side of the Torotorofotsy Wetlands and outside of the Mantadia-Zahamena Corridor, it does not fragment the protected areas.

Changes in stream flow or groundwater flow could occur to the Torotorofotsy Wetlands and streams flowing into the Mantadia-Zahamena corridor. These effects have the potential to cause changes to vegetation at the edges of the wetlands and streams.

The development of the mine will lead to an increase in the population of the area. This may result in additional threats on the protected areas, including land use from induced development, and higher tourism levels. These effects may be positive or negative.

The project has committed to protect two azonal conservation areas at the mine site and to assist with support for management of other protected areas in the RSA. This represents a positive effect for protected areas.

4.5.5.1 Assessment Methods

The assessment of effects on protected areas is based on:

- a physical analysis of extent of protected areas that the mine footprint will overlap in the LSA;
- the results of hydrology, hydrogeology and water quality analyses that indicate how water flow will be affected in the LSA; and
- socioeconomic impact information, which helps to determine indirect population effects on protected areas in the RSA.

Geographic Information System (GIS) software was used to conduct the spatial analysis of impacts to protected areas. The results of the modelling for hydrology, hydrogeology and water quality were used to discuss potential impacts on water for the Torotorofotsy Ramsar site. A socioeconomic model, discussed in Volume B, Section 5.1, was used to estimate population changes and this information was applied to the impact analysis for protected areas.

4.5.5.2 Assessment Criteria

The assessment criteria presented in Table 4.5-1 were used to evaluate impacts on protected areas.

Table 4.5-1 Impact Description Criteria for Protected Areas

| Direction | Magnitude | Geographic Extent | Duration | Reversibility | Frequency |
|--|---|---|---|----------------------------|---|
| positive: enhanced management of protected areas neutral: no change in protected areas negative: degradation of protected areas | negligible: no measurable effect low: physical effects on 1% or less of a protected area and/or minor indirect impacts moderate: physical effects of 10% or less of a protected area and/or moderate indirect impacts high: physical effects of more than 10% of a protected area and/or high indirect impacts | 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 |

4.5.5.3 Mitigation

The mine footprint will be kept at the minimum feasible size that ensures efficient, economic mine operation.

A water management plan for the mine will be implemented to ensure that flow rates into the Torotorofotsy watersheds remain consistent with levels within the historic range of natural variation. Sediment runoff will be controlled and levels of sediment and other substances in the water flowing into the Torotorofotsy Ramsar site and into the Mantadia-Zahamena Corridor will be kept within acceptable limits as determined by the needs of people and aquatic ecosystems. Additional mitigations relating to water management are provided in the hydrogeology, hydrology and water quality assessments (Volume B, Sections 3.7, 3.8 and 3.9).

The project will support the protection of two on site azonal forest habitat fragments and will provide support for management and planning activities or research in the Torotorofotsy Ramsar Site.

Watershed areas for the Torotorofotsy Ramsar site will be reclaimed to maintain long-term flow regimes and minimize siltation and water quality effects on the Torotorofotsy Ramsar site following closure.

Mine water management facilities will be engineered and constructed so as to minimize the risk of pond overflows. Details regarding this mitigation are provided in the natural risks and aquatic resources sections (Volume B, Sections 3.6 and 4.3).

4.5.5.4 Results

Effects on protected areas in the LSA and RSA must be viewed as part of the larger picture in Madagascar. The country places a high level of importance on protected areas and is now looking to expand protected areas to a total of six million hectares. The goal is to conserve both biodiversity and environmental systems such as watershed functions, both to protect the unique natural habitats in the country and to encourage tourism to support the economy.

Physical Impacts

The area to be affected directly by the mine overlaps the Torotorofotsy Ramsar site. Ramsar guidelines emphasize wise use, which is use that does not permanently alter the biological qualities of the site. To date, about 40% of the Ramsar site has been altered directly by human use, although these effects are

reversible. The project will impact an additional 3% of the Ramsar site (300 ha out of 9,300 ha).

Impacts on Water

The Torotorofotsy Wetlands and Mantadia-Zahamena Corridor will be affected by alteration in stream flow downgradient of the project, due to the diversion of headwater streams. However, site clearing will result in some increase in surface flow to the Torotorofotsy. The wetlands could also be affected by the loss of groundwater flow, as a groundwater depression is created around the mine. Overall, flows are predicted to follow historic seasonal variations during operations and closure (Volume B, Section 3.8). Indeed, then use of a Mangoro water supply pipeline, provides some flexibility in terms of mine water management. As knowledge about the functioning of the Torotorofotsy agro-ecosystem develops, it may be that the project can further manage water releases to the additional benefit of the Ramsar site.

Runoff from disturbed areas will be held in settling ponds during normal operations and released only when discharge water meets applicable standards. Water quality and flow will be monitored, including in the Torotorofotsy area. Depending on results, the need for biotic monitoring will be assessed.

Seepage or infiltration from the mine facilities has the potential to affect groundwater quality downstream from the mine area, and seepage to groundwater of waters that have been in contact with solute-generating materials will occur after facility closure. Predictions are that water quality off-site will be within international guidelines (Volume B, Section 3.9).

Indirect Social Impacts

Due to direct and indirect economic benefits of the mine, population levels in the Moramanga region are expected to increase.

The Torotorofotsy Wetlands may be affected by induced development, if economic development in the mine area leads to the construction of new communities in adjacent areas. Not all individuals migrating to the area will have employment at the mine, and many will be involved in agricultural activity to support themselves. Therefore, despite the development of management plans for this area, impacts relating to rice production and other use of the area may increase due to indirect social impacts.

Some beneficial results for the Torotorofotsy Wetlands may occur due to increased accessibility and publicity as a result of activities at the mine. Tourism

levels are likely to increase, including tourism from the employees at the mine. Tourism is a growing industry in Madagascar and this is a positive impact.

The Mantadia-Zahamena proposed conservation area is also likely to be affected by development induced by the mine, as the mine will be a strong draw for in-migration into the area.

Other proposed or existing protected areas within the mine RSA are Mantadia National Park, Analamazaotra Special Reserve, Anjozorobe Forest Corridor and Maromiza State Forest / private protected areas. These areas may experience small effects relating to increased tourism from the increased population with disposable income in Moramanga. Again, this is a positive impact.

4.5.5.5 Impact Analysis

Residual Impacts

Residual impacts on protected areas following mitigation are summarized in Table 4.5-2.

Table 4.5-2 Potential Effects and Residual Impacts for Protected Areas

| Project Period | Potential Effects | Mitigation | Residual Impacts |
|----------------|--|--|--|
| construction | clearing of the landscape and diversion of watercourses to holding ponds | erosion control; water management including no use of water from Torotorofotsy catchment for mine purposes; stable slope engineering | low magnitude/short-term physical modification of Torotorofotsy Ramsar site |
| operations | clearing of the landscape diversion of watercourses to holding ponds and impacts on water quality Indirect social effects of higher local populations establishment of azonal protected areas on site | erosion control; water management designed to maintain natural regime of watercourses in wetlands watershed; stable slope engineering; progressive reclamation forest management planning for areas around mine LSA n/a | moderate magnitude / medium-term modification of Ramsar site low magnitude / medium-term modification of hydrology of Ramsar site low magnitude / medium-term negative impact on protected areas in LSA positive medium-term impacts on protected areas in RSA positive long-term impact on preservation of azonal areas |
| closure | seepage of water from mine areas and effects on water quality | reclamation planning | negligible magnitude / long-term effects on downstream water quality |

n/a = not applicable.

During the construction phase for the mine, only a small area of the Ramsar site will be modified. Effects in this period will be low in magnitude and short-term. Land modification will occur on an intermittent basis and is considered medium in frequency. This effect is reversible and the environmental consequence is negligible.

During the operations phase for the mine, a maximum of 3% of the Ramsar site will be modified. This effect is considered moderate in magnitude and will be medium-term in duration. Land alterations will be medium in frequency and will be reversible. The overall environmental consequence of this effect is low.

Water runoff to the Torotorofotsy Wetlands will be carefully maintained during operations so that quantity of water flow is within the range of natural variation of the system in each season, and quality of water is within the most stringent of Malagasy and World Bank guidelines. The mine water management plan gives priority to maintaining dry season flows. However, the modification of the watershed may result in some small changes to the function of the system including some more high flows during the wet season. This impact is considered low in magnitude. The effect is medium-term in duration, occurs with medium frequency and is reversible. The environmental consequence of this impact is low.

The Sakalava Stream basin at Analamay feeds into the Mantadia-Zahamena protected area. Water management within this basin will cause some higher flows in the wet season, while maintaining flows within the natural range of variation in the dry season. Two kilometres downstream from the mine site, water volumes are predicted to increase by 10 to 15% in the wettest months (December, January, February and March). More detail on hydrologic impacts is provided in the hydrology section (Volume B, Section 3.8). Erosion control and the use of the Analamay northeast clarification pond system will mitigate sedimentation, and water quality monitoring will be conducted to evaluate water quality on a regular basis. This impact is considered low in magnitude, local in extent and medium-term in duration. The effect is not reversible, however, because water volume changes will continue past closure. The environmental consequence of this impact is low.

The indirect effects of migration of populations to Moramanga and the region around the mine are difficult to predict but are conservatively estimated to be low with respect to protected areas, after mitigation and land use planning occurs. These effects will be medium-term in duration, medium in frequency, and will be reversible. The environmental consequences of these effects will therefore be low.

The impacts listed above resulting from development of the mine site are not expected to adversely affect economic sustainability and tourism potential for the Torotorofotsy Ramsar site, the Mantadia-Zahamena Corridor or any of the other protected areas in the RSA. However, one additional effect on tourists in these protected areas may occur due to visual impacts, as described in Volume B, Section 3.10. Medium-term positive impacts are expected for regional tourism (to protected areas in the RSA). Long-term positive impacts are expected to result from the conservation of on site and off site azonal protected areas. Because these effects are positive, they are not rated in terms of environmental consequence.

At closure, through reclamation, most impacts on protected areas will become negligible. However, as discussed in Volume B, Section 3.8, higher flows are predicted for the wet season after closure.

Table 4.5-3 Residual Impact Classification for Protected Areas

| Phase | Direction | Magnitude | Geographic Extent | Duration | Reversibility | Frequency | Environmental Consequence |
|---|-------------------------|-----------|-------------------|-------------|---------------|-----------|---------------------------|
| issue: clearing or fragmentation of protected lands | | | | | | | |
| construction | negative | low | local | short-term | yes | medium | negligible |
| operations | negative | moderate | local | medium-term | yes | medium | low |
| issue: water quality and quantity changes | | | | | | | |
| construction / operations | negative | low | local | medium-term | no | medium | low |
| closure | negative | low | local | long-term | no | medium | low |
| issue: indirect impacts of social / population changes (land use modification) | | | | | | | |
| operations | negative | low | local | medium-term | yes | medium | low |
| issue: indirect impacts of social / population changes (tourism) | | | | | | | |
| operations | positive ^(a) | n/a | n/a | n/a | n/a | n/a | n/a |
| issue: direct protection of azonal areas | | | | | | | |
| all | positive ^(a) | n/a | n/a | n/a | n/a | n/a | n/a |

^(a) Impact classifications not applicable for positive impacts.

n/a = not applicable.

Prediction Confidence

The prediction confidence for this assessment is moderate, overall. Uncertainties arise from the uncertainties described in the water quality, hydrology, hydrogeology, and socioeconomic sections, which relate to potential effects on protected areas.

Additional uncertainties are associated with project mitigations, such as the implementation of the forest management plan, and the level of success of this plan with respect to land use activity in and around protected areas in the LSA.

4.5.5.6 Monitoring

Water quality for the water being released to the Torotorofotsy Wetlands system will be monitored as described in the water quality section of this volume (Volume B, Section 3.9). Water flow levels in the Torotorofotsy Wetlands will be monitored regularly to ensure that levels are within the natural range of variation as indicated by baseline data.

4.5.6 Conclusions

Low environmental consequences for protected areas will occur due to several impacts in the operations phase. The Torotorofotsy Ramsar site is expected to be impacted by direct clearing of a small part of its watershed, changes to water quality and quantity, and the indirect effects of increased regional population on local land use. The planned Mantadia-Zahamena corridor may also be affected by local changes in stream water quality and quantity, and the indirect effects of an increased regional population on land use.

Impacts during the construction phase are expected to be of negligible consequence.

Impacts following closure are expected to be of low consequence, and largely mitigated through reclamation.

Positive impacts are anticipated through increased economic input into protected areas in the RSA through tourism, and through the protection of azonal areas by the project.

The impacts resulting from development of the mine site are not expected to adversely affect tourism potential for protected areas in the RSA.

5.1 SOCIOECONOMICS

5.1.1 Introduction

The five communes of Morarano Gare, Ambohibary, Moramanga, Ampasimpotsy and Andasibe are the primary areas of mine impact. These communes are nearest to the mine site and can expect to see significant interaction with the mine in regard to economic opportunities, given agreement to provide training and employment locally. Moramanga, where all mine recruitment activities will occur, has a more diversified economy than other more rural communities and as a result may see comparatively more economic benefits. Because of their propensity to experience more negative impacts as well, it is these communes that will benefit from social mitigation and potential investments by the Ambatovy Project (the project) in the mine area. These communes also use land, water and forest resources with some potential to be negatively affected by the mine. Residents of these five communities will also be subject to the potentially negative project effects associated with in-migration. Fokontany within these communes that are closest to the mine site are more likely to experience negative effects. Baseline socioeconomic information has been provided in Volume K, Appendix 1.1.

5.1.2 Impact Mitigation and Benefit Enhancement

Socioeconomic mitigation and benefit enhancement will largely be planned and implemented for the project as a whole. While there are initiatives that are required specific to certain project components, and the potential for effects these components may individually have, most measures the proponent will undertake are applicable to all or almost all of the project components, at least in terms of objectives, principles and approaches. This section is general to all five project components, however where it is necessary to differentiate between components, this is noted. The impact mitigation and benefit enhancement matrix in Table 5.1-1 also provides additional detail on how the measures described below relate to the mine specifically.

Table 5.1-1 Impact Mitigation and Benefit Enhancement Measures

| Impact | Impact Mitigation and Benefit Enhancement Measures |
|--|--|
| Overall Project | |
| Employment | Local Resource Development Initiative (LRDI). Will include employment targets over time by job type and level, and training (in house and through Madagascar institutions) to increase a) number of Malagasy employees over time and b) level of jobs taken by Malagasy employees over time. Will differentiate between mine and plant, Moramanga and Toamasina contexts, and construction and operations. Will take into account training required to ensure that project operations do not use too many skilled persons in Toamasina to the detriment of other local businesses. Will include an element of support to local educational institutions such that employees are available to respond to potential for indirect and induced economic effects of the project. Offshore construction and operations contractors will be obligated to participate in LRDI as part of the terms of their contracts. |
| Procurement of goods and services | A Procurement Plan (PP) will identify Madagascar sources of supply for construction and operations goods and services. Will include measures to develop over time the capacity of Madagascar suppliers of goods and services. This could include, for example, breaking down procurement packages so that what can be supplied from Madagascar, or through Madagascar middlemen, is tendered locally. Or, for example, assisting potential Madagascar suppliers to joint venture with offshore suppliers. Offshore construction and operations contractors need also be obligated to participate in the PP. |
| Capacity building of labour force and businesses | None required additional to LRDI and PP, as above. As this is a longer-term objective, emphasis can be placed on those elements of construction phase that have longer term applicability to operations phase, and on operations phase. |
| National economic growth, including indirect and induced effects | None required additional to the PP, as above. |
| Fiscal benefits to governments | None required. |
| Strengthening of the mining sector | None required. |
| Improvements to national infrastructure | Planned interventions by the project in Madarail operations (construction, supply of capital equipment, management, etc). Planned interventions by proponent in access road construction. Potential provision of electricity to national grid. |
| Demonstration effect on potential for foreign investment | None required. |
| Mine Site | |
| Employment | LRDI, as above, with sections specific to mine operations and Moramanga context. |
| Procurement of local goods and services | PP, as above, with sections specific to mine construction and operations and Moramanga context. |
| Indirect and induced economic effects (on labour forces and businesses) of direct project employment and procurement | None required additional to LRDI and PP, as above. |
| Training and capacity building of workforces, businesses, local governments | None required additional to LRDI and PP, as above. Project involvement in regional planning initiatives as described below should have a positive effect on local government capacity. |

Table 5.1-1 Impact Mitigation and Benefit Enhancement Measures (continued)

| Impact | Impact Mitigation and Benefit Enhancement Measures |
|---|---|
| Local economic growth | None required. |
| Diversification of local economy | None required additional to PP, as above. |
| Increased local government revenue as a result of royalty distribution | None required. However, the project will consider assisting regions or communes with budgetary management, if requested. |
| Improvements to government services consequent on increased revenues from royalties | None specifically required. Project involvement in regional planning initiatives as described below should have a positive effect on delivery of government services. |
| Assistance with community development and local capacity building | Partnerships with communities, government and NGOs in community planning and development. Modalities for contributing to community development interventions to be identified, as well as the prospective role of the project, geographic target areas, priority areas for intervention (education, productive activity, health etc.) and delivery mechanisms in partnership with affected people, their governments and prospective partner organizations. |
| Support to regional planning initiatives | Contribution and modalities for supporting regional planning to be identified through consultation and partnerships with affected people, their governments and prospective partner organizations. Support to regional planning initiatives will include a component to increase the capability (capacity) of regional planners to fulfill their mandates. |
| Improved well-being associated with increased employment, incomes and improved service delivery | None required |
| Resettlement of a few households possibly needed | Resettlement Action Plan |
| Households and livelihood resources affected by linear development land and right of way requirements | Detailed alignment of linear developments (water pipeline, powerlines, roads) will avoid villages, individual households and agriculture land to the extent possible. Where this is not possible, compensation -- or at the limit resettlement -- commensurate with the level of loss of livelihood resources will be paid. |
| Disturbance effects associated with construction and operations activity, increased traffic congestion, noise, dust, changes to air quality, etc. | Full mitigation of environmental effects (so that there are no social effects to mitigate). Otherwise, construction and operations best practice. |
| Ground and surface water quantity and quality effects on livelihoods and health | Any needs linked to planned environmental monitoring of effects plus consultation. Depending on nature, either replacement of water resources or resettlement. Replacement will be "sustainable" i.e., rooted in local economy and managed locally rather than replacement water being procured and delivered by the project. The latter may be a short-term option pending a longer-term solution. |
| Loss of or reduced access to forest resources used to support livelihoods, as a result of both project land requirements and mitigation for biology effects | Involvement of stakeholders in buffer forest management planning aimed at reaching consensus. However, if needed, replacement of lost forest resources or provision of alternative resources. As above, replacement of same or alternative resources needs to be rooted in local economy and managed locally. |
| Pressure on agricultural and grazing land resources as a result of land use changes and some limited resettlement | No direct mitigation practicable. Pending consultation with communities, project can look toward promoting agricultural initiatives that will result in improved land management and productivity. Ongoing consultation and grievance mechanism can capture any particularly negative effects attributable to the project for adaptive management. |

Table 5.1-1 Impact Mitigation and Benefit Enhancement Measures (continued)

| Impact | Impact Mitigation and Benefit Enhancement Measures |
|--|---|
| Migration and consequent effects (see below for consequent effects) | Corporate policies on workforce management that directly or indirectly discourage migration developed and advertised. These would include such measures as no at the gate hiring, working with residents and local authorities to ensure that actual residents from the near by communes are identified and pre-screened for employment, minimizing contact between expatriate workforces and local economy, accommodation for out-of-area Malagasy workers, etc. Some level of migration will however occur, with potential negative effects on the local population that will need to be addressed through other means (see below). |
| Increase in incidence of HIV/AIDS and other transmissible diseases as a result of increased incomes, imported workforces, migration etc. | Implementation of aggressive workforce and public HIV/AIDS programming and enforced worker codes of conduct, all integrated with national and local initiatives to minimize the impact of the disease. |
| Threats to public health and safety as a result of increased incomes, imported workforces, migration, increased traffic, etc. | Workforce management, including cross cultural training and enforced codes of conduct. Specific interventions, pending consultation with communities, that targets public health may be a priority. Ongoing consultation and grievance mechanism can capture any particularly negative effects attributable to the project for adaptive management. |
| Pressures on local social and physical infrastructure (schools, health services, housing, etc.) as a result of migration | If efforts to control migration are not successful, the project will evaluate infrastructure impacts and support local efforts to address impacts. Pending consultation with communities, assistance with planning of social infrastructure and infrastructure investments, that targets health and education as a priority. Ongoing consultation and grievance mechanism can capture any particularly negative effects attributable to the project for adaptive management. |
| Inflation as a result of increased incomes and consequent increased demand for local goods and services | No direct mitigation practicable. Project benefits and assistance with community development initiatives should produce overall economic benefit to Moramanga area. Imbalances between supply and demand can be expected to equilibrate in short term. Ongoing consultation and grievance mechanism can capture any particularly negative effects attributable to the project for adaptive management. |
| Social conflict between introduced workers and local residents, and between family members, individuals, villages and communes | Workforce management policy for introduced workforces, including cross cultural training and enforced codes of conduct. Conflict between elements of the local population cannot be directly mitigated. Ongoing consultation and grievance mechanism can capture any particularly negative effects attributable to the project for adaptive management. |
| Cultural change | No direct mitigation practicable. Effects are unpredictable and will be both positive and negative. Ongoing consultation and grievance mechanism can capture any particularly negative effects attributable to the project for adaptive management. |
| Impacts associated with any real or perceived risk of accidents associated with mine site infrastructure, for both workforces and for the general public | Corporate health and safety policy, including health and safety training. Public education on actual risks. Emergency response planning. Medical insurance for employees, including disability insurance. Provision of on-site medical facility. |
| Closure and consequent economic and social effects | Corporate sustainability policy. Integrating acknowledgement of eventual mine closure in all social investment plans. |

As context, the primary differences with respect to socioeconomic effects between the different components are listed below:

- The mine and tailings/plant areas are likely to experience the full range of positive and negative effects that large projects introduced into rural environments can have. This includes resettlement, the planning (mitigation) for which is described in a separate Resettlement Action Plan.
- The pipeline will experience primarily short term, construction phase effects. While mitigation and benefit enhancement as described below will be applied to the pipeline, given that long-term effects are largely negligible, emphasis in the delivery of what follows will be at the mine and tailings/plant sites.
- Toamasina, as a large urban centre, will especially benefit economically from the project. Whereas there is potential for the change implied by an improved city economy to negatively affect some people, and the proponents would expect to address those effects as possible, they are more in the nature of effects common to any kind of significant economic boost.
- Job availability will be highest at the plant site; less numerous at the mine site. Job availability along the pipeline will be mainly short-term during the construction phase.

5.1.2.1 Principles and Objectives

The following principles guide the development of social impact mitigation and benefit enhancement:

- Communities and people most likely to experience negative effects of the project will receive project benefits preferentially. However it is also in both the proponent's and the Government of Madagascar's interests to ensure that project benefits are distributed more widely in the country. This implies that whereas rural communities in the mine site and tailings/plant site areas will be accorded priority in the distribution of project benefits, there is recognition that where local residents are unable to take advantage of benefits, measures should be in place to distribute these more widely in Madagascar.
- Consultation and participation will be practiced throughout the project life to define priorities, needs and preferences, and to decide what and how mitigation and enhancement measures will be implemented. Mitigation and benefit enhancement as described below has not yet been developed in detail. This will be done during further consultation with affected people.

- The development and implementation of mitigation and enhancement measures will be undertaken in partnership not only with communities, but also with a range of organizations from government and civil society that are able to bring culturally appropriate experience and knowledge to maximizing net socioeconomic benefit. This also will ensure that initiatives undertaken by the proponents are consistent and complementary to ongoing planning and implementation of social and economic development by local, regional and national government agencies.
- Planning and implementation of both mitigation and benefit enhancement measures, but also of all project operations, will be conducted in an environment of accountability and transparency. This will include public reporting on programs, funding and results for mitigation and benefit enhancement measures, as well as facilitating access to the proponents on the part of communities and their governments in the event that unforeseen negative effects occur, or grievances develop. This was a need emphasized during consultation (Volume A, Section 6).
- Sustainability criteria will be incorporated in decisions on mitigation and benefit enhancement measures, by considering:
 - demonstrated demand for the measure;
 - affected people's willingness to participate in the planning and implementation of the measures that imply their participation;
 - consideration of changes that will occur with closure such that projects do not depend on Ambatovy Project contributions over the long term;
 - fair distribution of projects across affected populations;
 - consistency with government planning; and
 - financial sustainability through user pay principles and/or integration of projects into existing government and/or civil society systems.

The main objectives of impact mitigation and benefit enhancement are as follows:

- mitigating the impacts and enhancing the benefits of project development;
- creating opportunities for people local to the project area to participate in the project, thereby enhancing self-determination and sustainability;
- establishing the Ambatovy Project's role as an active member of the community and participant in the sustainable development of Madagascar; and

- maintaining goodwill and good relations with communities and their governments.

5.1.2.2 Preferential Employment, Business Opportunities and Training

Employment

The project's employment policy is to maximize employment of people of Madagascar and local to the project, towards ensuring that project benefits accrue both to the Madagascar economy, but also to the local economy and to its population. Such a policy implies that where people have little experience with the mining sector, project-specific initiatives can be required to remove barriers to employment. In the mine site context, "local" is determined to include Moramanga, where it is expected that most skills will be sourced. People in the project's immediate vicinity, however, will benefit from academic and skills upgrading and job opportunities. However, in order to limit the effects of uncontrolled labour migration to nearby communities, recruitment activities will occur in Moramanga.

It is important to the local population that the project not conflict with subsistence activity that is economically, socially and culturally important to livelihoods and individual and commune cultural identity. Under-representation in the workforce by women may be for lack of opportunity rather than lack of a desire to participate (Volume K, Appendix 1.1). Many of the better jobs at the mine will require at least a high school education. There are therefore potential barriers to employment of many local residents with the project.

The Ambatovy Project will develop a Local Resource Development Initiative (LRDI), which will be put in place to enhance employment through human resource policy and procedures, and may include the following:

- Analyzing the barriers to employment (including barriers related to gender, literacy, education and skill levels, culture and social practices, etc.) relative to project workforce requirements, and developing a strategy to overcome those barriers.
- Establishing achievable targets that grow over time for percentages of the workforce that a) are locally recruited and b) are recruited in Madagascar including by skill level.
- Specifically at the mine site, establishing a system to ensure equitable distribution of available jobs among the rural communities affected by the project.

- Providing full and easily accessible information on workforce requirements, job descriptions, qualifications and performance criteria. Community relations staff will be available at the facility recruitment centres to assist potential employees with applications.
- Screening all applications for employment for residence and, where equally competent preferentially selecting residents local to project activity as candidates for job openings.
- Reviewing educational and training requirements for project positions and conducting prior learning assessments, with a view to accepting experience in lieu of qualifications where this is possible considering operational requirements.
- Putting in place pre-employment programs to encourage primary and high school completion, skill training, on the job and management training programs to enhance local employee recruitment, retention and promotion.
- Conducting exit interviews with a view to increasing the understanding of barriers to successful long-term employment, and integrating the results into other initiatives as relevant.
- Providing cross-cultural training to all employees in order to facilitate the integration of local employees into the workforce.
- The above are not easily applicable to the construction of the pipeline, which will see only short-term employment opportunities for people in any one location. Local resource development will include an undertaking to ensure that most unskilled positions are filled by those in the immediate vicinity while taking measures to discourage labour migration to the near by communities.

Business Opportunities

As for employment, the project policy is to maximize opportunities for businesses both in Madagascar and local to the project to provide goods and services, again in the interest that project benefits accrue both to the larger national economy, and to the economy and people of local areas. Where local businesses are small (SMEs) and/or have limited experience with the mining sector, project-specific initiatives can, over time, remove barriers to successful bidding on procurement contracts. The proponent will develop such initiatives within the Ambatovy Empowerment Program (Volume G, Section 4.1).

Particularly near the mine site, but also in Toamasina, there are limited businesses operating at the present time with the capacity to meet the needs of a large mining project. There is limited experience with the management and logistics of procurement, including preparing offers of goods and/or services.

The businesses that do exist tend to be small, and do not have the breadth or the financial resources to bid on large contracts. They have limited experience with the exigencies of supplying large, time-sensitive operations and limited experience with quality control.

The project will develop a Procurement Plan (PP) which will enhance the participation of Madagascar and local business in the project. PP initiatives will include elements such as:

- Analyzing the barriers to supply of goods and services by Madagascar and local businesses relative to project procurement requirements, and developing a strategy to overcome those barriers.
- Providing in monthly notices distributed to interested businesses full and timely information on procurement requirements in areas for which the business inventory indicates there is some potential for local supply (including for example transport and logistics; consumables supply; office equipment and furniture; printing and publications; training and professional services; clothing supply; and catering).
- For any contracting opportunity in areas for which the business inventory indicates local capacity to supply, establishing a contracting policy that responds first to an indication of local business interests, entering into good faith negotiations with that local business and then only in the event of no success, moving to bidding elsewhere.
- Developing and supporting training programs for existing and potential entrepreneurs, particularly SMEs that will contribute to their success rates at offering goods and services to the project and to the broader market.

Education and Training

In addition to facilitating access to project opportunities as above, the project recognizes that limited educational achievement contributes to lack of economic opportunity more generally. This need has been frequently raised during consultation (Volume A, Section 6).

The project will develop a Training Plan which will be put in place to enhance the earliest uptake of project economic opportunities by workers and businesses. The Training Plan envisages an expenditure of at least \$10 million over the life of the project on education and training directly related to project needs. In addition, as part of a broader education and training strategy, initiatives may be put in place intended to address not only longer-term project requirements for a skilled local labour force and business community, but also to contribute to people's participation in the broader wage and rural economies in the interests of sustainable development. The project expects to work in partnerships with local

communities, educational institutions and authorities to develop the details of employee, business and general population education and training that is broad-based in its goals and objectives. Training centres will be established in appropriate areas to enable local recruitment and provide necessary skills training. Project participants will receive general orientation training and basic training in Health and Safety policies and procedures relative to their areas of work. Training will be provided in technical areas such as piping, mechanical trades, electrical trades and equipment operations. Other programs will provide skills training in administrative areas such as clerical and industrial relations management and also general job skills such as camp maintenance and catering. To meet longer term human resource requirements and to contribute more broadly to the achievement of community objectives, the proponent will partner with organizations to provide general education and pre-employment training. Potential examples are identified below:

- School-based contributions and programs that encourage students to stay in school, enhance the quality of education they receive and enable them to pursue higher education.
- Summer employment programs and cooperative education opportunities at the project facilities to provide job experience to youth.
- Pre-employment training for people who wish to prepare themselves to enter the wage economy, whether this is to work for the project or to seek employment elsewhere.
- Support for primary and high school completion programs for the project employees who do not meet the educational requirements for more senior jobs but are otherwise good candidates for promotion.
- Assistance programs to educational institutions and organizations and to business associations in Moramanga and Toamasina to develop employment oriented training as required in specific mitigation for the potential effects on local businesses of attractive employment by the project that has the potential to create a labour shortage for existing businesses.
- Establishment of technical training programs (in technical trades, equipment operation, computers and office skills, security, health and safety, environmental services, etc.) that permit the project employees and/or individuals who are otherwise good candidates for employment to obtain technical qualifications to enhance employment and promotions.
- Including in job responsibilities for expatriate personnel the requirement to mentor Malagasy staff such that they may advance.
- Implementing the above training programs in cooperation with local educational institutions and organizations, as a contribution towards

improving the breadth and depth of post-secondary education in Moramanga and Toamasina, as well as Madagascar more generally.

- Working with other mining sector organizations in the region, and offshore contractors to the project, to enhance education and training strategies across the sector, through sharing of best practice and resources.

5.1.2.3 Workforce Management

Consultations indicate concerns about the potential effects of the introduction of large numbers of out of area workers on public health, delivery of social and physical infrastructures and services, social values and cultural integrity (Volume A, Section 6). Workforce management policies will be implemented to manage the contact between the residents of areas local to project activities and the out of area project workforces (expatriate or from elsewhere in Madagascar), to control inappropriate behaviours of those workforces and to limit the potential for in migration of people without employment offers. Workforce management measures will include:

- Implementation of a formal application and recruitment process which a) when selecting between equally competent people, gives priority to local residents, and b) recruits others in out of local area urban centres. Application and recruitment policies will be designed to discourage to the extent possible any speculative migration in search of employment with the project.
- Measures to address the migration issue in construction contracts.
- Clear communication to local governments and populations through regular consultations, in advertisements for job openings through media (i.e., newspapers and radio) and in all information materials distributed by the project (i.e., newsletters and media interviews) and on preferential employment policies and recruitment methods.
- Where applicable, establishment of fully serviced workers' camps for out of area employees that meet all worker non-emergency needs for accommodation, food, healthcare and recreation, with no need for recourse to local communities.
- Establishment and enforcement of codes of conduct governing the behaviours of not only out of area workers, but all workers, both while working and while en route between their homes and project sites.
- Cross-cultural training of all employees to encourage mutual understanding and respect for local culture.

5.1.2.4 Mitigation for Potential Effects on Natural Resources

The project will require land at the mine site, along the pipeline route, and at the tailings/plant site, land that is currently used to some degree by populations nearby. In addition, the project is expected to have isolated effects on water quantity and quality at the mine site and at the tailings site and will be closely monitored. Finally, in an effort to mitigate potential effects on biodiversity at the mine site there will be a forest management plan to foster sustainable use for long-term benefit. Local stakeholders will be part of that co-operative forest planning process (Volume H, Appendix 6).

People within or in close proximity to any of the developments whose livelihood strategies are impacted could be resettled in accordance with the resettlement action plan. Some situations may arise that do not warrant mitigation at the level of resettlement, but do require some redress in the form of socioeconomic mitigation.

In regard to forest access, in most cases forest use of land affected by the project is not extensive. People are more likely to use forest resources closer to their homes, where forests do in fact demonstrate much more use, including use that is threatening the stability of the forests. It is envisaged that consultative planning and implementation of a sustainable forest management plan can in the longer term enhance the use of forests for livelihoods.

There will likely be individuals who will be unable to continue to engage in certain forest-based economic activities, whether conducted sustainably in what is still the undisturbed forests that will be affected by the project or in the disturbed forest for which rules of access may change. The project's community relations staff at the mine site will ensure that in such events:

- People are encouraged to come forward with demonstrations that forest access has been curtailed at some economic cost.
- Any such claims are investigated in a timely fashion, in conjunction with a formal grievance and dispute resolution mechanism (see below) where necessary, such that claims can be resolved at no cost to the claimant.
- Where forest resources are demonstrated to have been affected by the project with a resultant economic effect, means are negotiated to mitigate that effect, either by replacement by the project of the resources, assistance to the claimant to replace the economic activity with an alternative, or compensation.

- Care will be taken in the above to plan any mitigation in such a way as to enable the claimant over the medium term to maintain economic well-being without becoming dependent on resources provided by the project on a regular basis. This could include for example negotiating rights for the claimant with respect to any forest management plan, training to find an alternative economic activity, establishing alternative pasture systems, plantations or gardens to ensure a source of forest products, etc.

With specific regard to water resources, this is of concern at the mine site and at the tailings facility. The impact assessment concludes that downstream water effects, while not of consequence when assessed on an annual or seasonal basis, may at specific times result in a) surface water deficits (tailings area) and/or b) excess surface water flows (mine area) that may be of consequence to farmers. It is also likely that irrespective of actual effects on the hydrological regime, people will perceive water quantity problems to be attributable to the mine and tailings.

There will be individuals who experience or perceive water effects that in turn affect economic activities and/or health, including paddy rice and baiboho cultivation, fishing, water supply for small livestock, and water supply for domestic uses. The project's community relations staff at the mine site will ensure that in such events:

- People are encouraged to come forward with concerns that water effects are in turn having economic or health effects.
- Any such claims are investigated in a timely fashion, in conjunction with a formal grievance and dispute resolution mechanism (see below) where necessary, such that claims can be resolved at no cost to the claimant.
- Where water supplies are demonstrated to have been affected by the project with a resultant economic or health effect, means are negotiated to mitigate that effect by the project, or compensation in the event of economic effects.
- Where water supplies are thought not to have not been affected by the project, this is either satisfactorily explained and accepted by the claimant, or there is recourse to assist with water management such that the claimant can be confident the project is not materially affecting economic well-being. It is noted that whereas there are areas well beyond any potential project effect for which claims are likely to be judged spurious, there is a zone of uncertainty between the boundaries of the project footprint and floodplains up to 10 km downstream in the six watersheds potentially affected by the mine site.

- Care will be taken in the above to plan any mitigation in such a way as to enable the claimant over the medium term to maintain economic well-being without becoming dependent on resources provided by the project on a regular basis. This would likely most importantly include assistance with water management.

Overall, it would be the proponent's intent to fully mitigate any economic effect, and to take into account any cultural loss that may be experienced proportionate to the reduction in the resource base.

5.1.2.5 Contributions to Infrastructure

The project description includes information on planned interventions to improve national infrastructure in so far as this is coincident with project requirements (rail, port and roads). These improvements will constitute a project benefit to Madagascar beyond contributions to the success of the project.

In addition, the proponents will investigate options with regard to providing and cooperating with government to ensure long-term maintenance of access roads along the eventual pipeline route. Pipeline construction will require building roads, and these will be planned to facilitate permanent infrastructure where possible. Populations along much of the pipeline route experience constraints to livelihoods through a difficulty in getting surplus agricultural production to market, as well as quality of life constraints through reduced access to health care and education services. Remoteness and lack of access to regional administrative centres also implies lack of access to a host of other potential government services, from agricultural extension to resource management.

While the construction of access roads may have implications for biological integrity – permitting as these do access to new areas for potential over exploitation of forest and other natural resources – the project would expect to work with authorities to minimize potential negative effects of road construction in order to benefit populations local to the pipeline route.

Communities along the pipeline route will see disturbances to land and water resources as a result of pipeline construction, and as result of the construction of access roads. Such disturbances will be compensated, and with the completion of the construction of the buried pipeline, most land uses, and all uses of water resources, will be possible again. The planning of access roads to provide permanent infrastructure is intended to provide both mitigation for short-term nuisance effects and benefit enhancement to potentially affected populations to improve quality of life over the long term.

Finally, it is possible that when access roads, water and slurry pipelines and powerline alignments are finalized in detail, some infrastructure may be affected. The project would intend to avoid any such effects to the extent practical, but will replace any infrastructure that must unavoidably be moved.

5.1.2.6 Public Health and Security Effects

There is an association of particularly large temporary, single status construction workforces, and out of area workforces in general, with not only socially disruptive behaviour such as problems with alcohol and prostitution, but more importantly with an increase in the incidence of HIV/AIDS. With all due consideration, the proponent will implement strategies to ensure workers act responsibly. The project has an HIV/AIDS protocol and is in the process of developing a comprehensive HIV/AIDS prevention program. While there are concerns about human rights as these may be affected by specific initiatives intended to control HIV/AIDS, the proponents consider that the risks to the population of Madagascar, until now comparatively HIV/AIDS free in the African context, warrant measures with regard to the import of foreign workers that would not be considered appropriate in their own countries. The project will ensure that action taken under the HIV/AIDS program will be consistent with Malagasy Legislation.

HIV/AIDS programs may include:

- The full range of best practice developed to date, including public education programs, voluntary testing, free condom distribution, peer to peer counseling, protection of employment and worker treatment.
- Provision of anti-retroviral therapy, including support services, to individual employees and their family members who may contract the AIDS virus.

While HIV/AIDS is the most alarming potential public health and security effect, there are others. The areas potentially affected by the project do not report many problems with theft, prostitution, alcoholism, domestic abuse and other violence, family breakdown or other social problems. Many of these are generally associated with either extreme inequalities of income or increases in disposable income. Individuals make choices in the face of economic and social realities that are not within the control of the project. To the extent that such unfortunate choices are made by individuals in the employ of the project, regular workplace employee assistance programs will be of assistance. Problems that can be attributed to the project will be addressed through various mechanisms including grievance and dispute resolution systems and assistance to community based organizations that currently deal with public health and security issues. The

project will ensure that despite the potential for such problems, communities near the mine will see overall net benefit.

While not impacts as such, there is also some potential that project risks, such as accidents, spills and other risks as identified elsewhere in the EA, could be realized with potential effects on not only public health and safety, but also livelihoods. Emergency response planning will include a public education component to advise people of risks, how to avoid these, and how to respond should a risk be realized.

5.1.2.7 Community Involvement

Over and above specific mitigations, the project will consider to provide planning assistance and capacity building as a contribution toward enhancing the net benefit of the project. Until the approach and needs are more fully defined through consultations between the project and the full range of potential participants, details cannot be prescribed.

The work of socioeconomic consultants and of the project's community relations staff at the mine site and in the Toamasina area has provided information on community perceptions of needs, much of which is included in the consultation sections (Volume A, Section 6), the baseline discussion and reports in Volume K, Appendix 1.1. Concerns centre on i) accessing economic opportunities, including access to employment, education and support to businesses towards economic diversification; ii) issues related to access to land, forest and water resources and the livelihoods that depend on these; iii) issues related to public health; iv) social and cultural issues; and v) support to decentralization and development planning.

The socioeconomic impact assessments in Volumes B to F note expected impacts, and also the potential for negative impacts that are not within the direct control of the project to fully mitigate. The most difficult of these include migration to the mine and tailings/plant sites (and consequent health, service delivery, resource and economic effects); induced urbanization at the plant site; and economic and social change that will certainly benefit many but can also disadvantage others.

Taking into consideration both articulated priority needs on the part of affected populations and the actual and potential negative project effects, potential areas for planning and assistance are briefly described below.

Education and Training

Given the high unemployment rates and the evident out migration of younger adults particularly around the mine site, it is perhaps not surprising that employment – and preparing for employment of what is, with the exception of Toamasina, a largely agricultural workforce – has emerged as a major need. Employment is constrained by several factors, most of which are inter-related.

For the largest fraction of all populations affected by the project, the challenge is not simply to provide mine-specific training, but to bring the general educational level up such that people have the basis (including literacy and numeracy) required to take advantage of project training opportunities. Economic hardship often results in children dropping out of school to work. Rural populations have difficulty educating their children beyond primary school. The lack of preparation for employment is thus potentially a long-term problem. Support to schools to improve completion rates as well as to include curriculum elements appropriate to children's needs and goals could be provided through involvement with stakeholders, local governments and businesses.

Productive Activity

It is clear from the baseline studies that poverty is experienced by very many people living around project sites. Increasing the return to labour, whether this return is in subsistence resources or income, is therefore a priority.

Productive activity in the agricultural sector is firmly linked in commune development plans with management of water. The project could support existing efforts to improve infrastructure as well as agricultural extension programs to increase what are comparatively low yields even in years when good growing conditions prevail. Capacity building and training of small business development, including agricultural product processing and particularly the artisanal work of women, could be included as part of the proponents project training and credit programs. Forest-based economic activities could be supported through assistance with sustainable management of forest resources and marketing of forest products. As the project is committed to providing technical assistance and advice to enable competitive participation for potential suppliers to the project, there are opportunities to share business advice and experience with these other sectors.

Health Services

Health service delivery is severely constrained throughout the project area, for reasons of distance, cost and quality relative to the health needs of populations. As a result, the primary causes of both morbidity and mortality are preventable

diseases such as malaria (Volume K, Appendix 1.1). The project has potential to affect human health in multiple ways. Increased incomes and provision of health services to employees and their families will be of benefit. However, the broader effects could be negative, from the point of view of disease. The project could assist in such areas as health education and technical assistance to strengthen service delivery.

Preservation of Social Values and Cultural Integrity

Of major concern to local populations are social and cultural issues. It is largely felt that whereas there is a need in the area for economic diversification because of pressures on agricultural economies and the employment needs of particularly the youth, there is also a desire to achieve this without changing the values and patterns of life. This can be challenging in the case of a project as large as this, which will have its highest effects on social and cultural issues in the rural economy around the tailings/plant site. What exactly may change, in what ways and with what effect is difficult to predict and mitigate. Monitoring needs are discussed below.

Support to Commune and Regional Planning

Madagascar is in a process of decentralization that has seen the establishment of multiple planning agencies with little capacity, technical or financial, to implement plans that have been developed (Volume K, Appendix 1.1). The project will offer participation in planning to those agencies involved in the implementation of programs if needed.

5.1.2.8 Closure Planning

The socioeconomic impacts of closure are felt in the coming to an end of employment and business opportunities created over, in this case, a period of about 27 years at the mine site and potentially longer in the Toamasina area, and the consequent negative social impacts of an economic downturn. The challenge is to ensure that in the process of enhancing local access to project opportunities during the project life, consideration is always given to its eventual closure. By the time of project closure the intent is to have increased the capacity of local communities to engage in agricultural and other economic activity that is independent of the project, and to have increased the economic and social well-being that provides a buffer against closure.

The measures described above for employment, business, education and training and social investment include several components that are intended to realize this

intent. The closure of the project will inevitably cause dislocation, however, this dislocation should be attenuated if the following interventions are successful:

- Preferential employment and training programs, as well as enlightened employment practices that contribute to job satisfaction, retention and promotion will build capacity to participate elsewhere in the wage economy. A constructive workplace experience will give people a competitive edge in later competing for jobs elsewhere in the economy.
- Preferential contracting of local business and assistance with the development of those businesses will build experience and competitiveness.
- Education and training programs that emphasize not only preparation of adults for work for the project, but encourage the young to value education with a view to either project employment or other participation in the wage economy has implications for long-term employability. The expectation is that school based programs will provide motivation to higher education not only in mining related fields but also in other areas.
- Participation in community development efforts according to priority needs while incorporating sustainability principles will enhance not only economic but also the social and cultural well-being, which underlies the ability of a population to create and take up life opportunities.
- Career counseling at the time of closure will assist employees in finding alternative employment.

5.1.2.9 Socioeconomic Monitoring and Consultation

Monitoring

In order for the project to ensure it delivers benefits, activities must be monitored. Monitoring is necessary to determine the effectiveness of mitigations put in place to address socioeconomic project impacts and to establish trends in well-being. The primary objectives of socioeconomic monitoring are thus to:

- record the uptake of employment, business and training opportunities over time and analyze the trends in this uptake in relation to expectations and targets;
- monitor the implementation and effectiveness of socioeconomic impact mitigations; and
- evaluate the trends in local economic and social development and well-being, as well as the relationship between these and project operations.

Monitoring, and the disclosure and feed back of monitoring results, will generate the information the project and the people and governments of project-affected communities will need, to establish compliance with undertakings in this document.

The socioeconomic monitoring plan is presented in three components. The three components are i) operations monitoring, to report on project inputs and results in relation particularly to economic benefits and public health and safety but also in relation to compliance with other undertakings; ii) monitoring of the effectiveness of socioeconomic mitigations in minimizing impacts and enhancing project benefits; and iii) monitoring for adaptive management such that the project is able to respond to any evolving change in project-affected communities.

Operations Monitoring

The proponents' own records on its operations will provide much monitoring data on undertakings described in this section, and subsequent undertakings in relation to other mitigations to be put in place. Such records include for example those on human resource and procurement activities, mitigation of any natural resource effects, and measures taken to prevent labour migration. In this regard, the project undertakes to:

- Maintain full human resource records in a form that will permit an annual roll-up of selection, employment, promotion, training and exit statistics on the workforce by residence, gender, level and field as a percentage of the total workforce.
- Maintain procurement records in a form that will permit an annual roll-up of the number, value and general content of contracts for goods and services by supplier location and ownership, as a percentage of total procurement.
- Require of all contractors and subcontractors annual reporting on employment and procurement that provides the same information.
- Maintain health and safety, accident, breach of worker codes of conduct and any other relevant records pertaining to events that occur in direct relation to project operations.
- Flag any anomalous results of traffic, air quality, noise and water quality monitoring programs, as described elsewhere in this EA and accompanying reports, in order to permit an assessment of potential for socioeconomic effects.

- Maintain records on all public education and information disclosure events (such as public emergency response training for example), including the content of programs and participation rates in programs.
- With agreements on compensatory measures to address any effects on people's use of land, forests and water resources, maintain full records on the delivery of proponents' obligations under these agreements.
- Maintain records on assistance given to planning and other community development initiatives (over and above specific mitigations).
- Maintain records on all formal consultations, meetings, and grievance and dispute events with the public, governments, partner organizations, the project workforce and contractors, noting attendance, issues raised and resolutions.
- At least on an annual basis undertake a formal review of the results of the above to determine the degree of compliance with EA-related undertakings, and to identify any specific obstacles or problem areas and any systematic successes or failures.

The above monitoring will be managed and administered by the proponents, in so far as it consists of the reporting of internal management information. The project will communicate the results internally to management and its workforce as appropriate, such that the information can be used to adjust policies, procedures, mitigation and enhancement measures and workforce behaviours where adjustments are identified to be necessary. The results will also be annually reported in an appropriate form and discussed with project-affected people and their governments with a view to maintaining an environment of transparency and accountability, and to building confidence in the project's economic and social performance relative to commitments.

Monitoring the Effectiveness of Socioeconomic Mitigation and Benefit Enhancement Measures

In addition to the above, the project will participate with people in project-affected communes, their governments and any relevant partner organizations in a third-party monitoring process to examine the effectiveness of mitigation and benefit enhancement measures targeted to address potential project effects. This monitoring will make use of the results of operational monitoring as described above, but in addition collect and collate additional data specific to proposed measures and incorporate a consultation component. This monitoring will analyze such information with a view to establishing whether or not specific mitigations are effective in achieving their desired outcomes.

The socioeconomic mitigations that require some monitoring effort beyond the operational monitoring include pre-employment training and other education programs, such as support to keeping children in school and public education in health; HIV/AIDS programs; workforce management in so far as this may effect quality of life in nearby communes; construction and maintenance of the pipeline access road; and natural resource compensation agreements. These are specific measures being put in place by the project to achieve specific objectives and can be evaluated as to the degree to which these objectives are being met.

The project will contract for the services of a specialist third-party organization, to develop a monitoring program to be implemented at least annually during the first five years of the project, beginning with the construction phase. Subsequent to the first five years, additional monitoring requirements will be discussed with project-affected people and local authorities.

Some of this will prove challenging. As an example, consider the effectiveness of HIV/AIDS programs in the Toamasina area. We do not have good baseline data on current HIV/AIDS rates, but the suspicion is that despite Madagascar generally low rates of prevalence, the situation at Toamasina may be somewhat worse. Baseline information needs to be collected and the HIV/AIDS program needs to be developed in detail, including targets relative to baseline information. Subsequent incidence rates, within and outside the project workforce would represent a good indicator of program effectiveness, but the degree to which the project has contributed to incidence will be hard to disentangle from other contributing factors.

As opposed to the operational (i.e. compliance) monitoring, the monitoring of the effectiveness of many socioeconomic mitigations requires specialized expertise working with affected people and agencies to establish the detail of the monitoring program. To be most effective, such monitoring would seek to ensure affected people's participation in the selection of indicators, the collection of data and the interpretation of these data.

Monitoring for Adaptive Management

This EA has come to a number of conclusions about the probability and mitigability of several other potential effects – on individual, family and community economic, social and cultural well-being – which also need to be included in a socioeconomic monitoring plan. These conclusions most importantly are that i) overall net positive effects are likely, although there may be negative dimensions at the individual and/or community level that are part of an overall net improvement; ii) many such negative dimensions are unpredictable in their detail; and iii) there are no obvious means of mitigating these, without

knowing what they actually turn out to be. Although there is experience in identifying indicators of well-being, it has proved extremely difficult to understand cause and effect.

Irrespective of directly attributable cause and effect, it is in the interests of the proponents to understand socioeconomic trends such that where the project is able to intervene effectively, it has the information to do so. The project has a long-term interest in healthy communities. In addition, putting in place a monitoring framework that attempts to understand cause and effect is important to both the project and affected people, as a contribution both to maintaining a constructive relationship between affected people and the project and to adjusting project mitigations in response to evolving impacts.

Monitoring perceptions, through ongoing consultation with affected populations, is also important. The continuity of social values or the levels of disturbance related to behaviours of out of area workforces for example are primarily subjectively experienced. The project's ongoing consultations with its workforce and affected people will provide some such information.

Insights from other international studies can inform the interpretation of data collected in the areas of project activities as described above. The monitors would include review of such studies in deliberations on the cause and effect relationships between project activity and community well-being indicators.

5.1.2.10 Ongoing Consultation

Consultation throughout the life of the project is critical to mitigation and benefit enhancement implementation and monitoring (Volume A, Section 6). The project's consultation program has been planned to provide people with mechanisms they will need to participate in project decisions that affect them. Information disclosure will continue to provide the information people will need to do this from an informed position. There is clear demand on the part of affected people for both more information on the project and for more clarity on means to approach the proponents with new concerns, which has been taken into consideration in identifying consultation and information disclosure activities as described below. Undertakings with regard to public consultation include:

- Public meetings at the commune level with project-affected people and their representatives at least twice annually.
- Meetings with sub groups, for example with businessmen, women or farmers, of the population at large where issues or opportunities arise.

- Formal meetings, on schedules to be negotiated, with government and with relevant partner organization.
- Distribution of periodic newsletters relating to the project.
- Clear notification on key project contracts.
- Maintenance of a public consultation database that will record all the above events, issues raised and undertakings to resolve these issues.

5.1.2.11 Grievance Procedures and Dispute Resolution

Any project complaints will ideally be resolved through informal means in the course of regular consultation. A formal mechanism to launch a complaint will also be available. In both instances, the concerns will be registered and tracked to their resolution. The project will establish a formal mechanism before construction begins to hear grievances and resolves disputes in a timely and satisfactory manner. In principle, such a mechanism would have:

- A simple process to lodge a grievance, either verbally or in writing, taking care to ensure that everyone finds the process accessible.
- Clear roles relative to addressing the grievance for each of the person lodging the grievance, commune government representatives and project representative.
- A time frame within which a response to the grievance is provided.
- An appeal process based on mediation or arbitration, with clearly defined time frame.
- A system to record all grievances, disputes and their resolution.
- Agreement on how the costs of grievance resolution are to be shared.
- Means of ensuring feedback to project operations of where systematic grievances are being observed.

5.1.2.12 Summary

As noted in the introduction to this section, most of the above measures will be applied to most of the project components, although the application may be somewhat different in detail, depending not only on the exact nature of impacts as they evolve, but also on preferences of affected populations on how to manage those impacts. Table 5-1 links impact mitigation and benefit enhancement measures for the project as a whole and then for the mine site specifically. Similar tables are provided in the project volumes for the other project sites.

5.1.3 Impact Assessment

5.1.3.1 Economic Opportunities

Consultation results indicate that economic opportunities created by the mine are a main concern of people. This includes people who do not expect to directly benefit but are interested to see that economic opportunities alternative to agriculture accrue to youth.

Consistent with the principles of cost-effective, efficient, and safe operations, the project intends to extend on a preferential basis employment, and business opportunities to mine site communes and nearby urban centres such as Moramanga. The project will also provide training and other assistance to mine site communes to help their residents take advantage of these opportunities. Finally, the project, when evaluating proposals for work on the project, will consider the extent to which its suppliers and subcontractors employ and contract Moramanga and businesses.

The extent of positive impacts of employment and business will depend on the success of these measures. There has been some experience with employment of people and supply of goods and services local to the project during the exploration phase. Most hiring to date has been from Ambohibary and Moramanga, although some individuals from other communes have also been employed, as well as from elsewhere in Madagascar. Geological and environmental technicians, drillers, heavy equipment operators, tradesman, and labourers have found work on the exploration phase of the project. Goods and services have been purchased widely and include fuel, food and accommodations, transport and drilling services.

Employment

There are challenges to hiring many of the required construction and operations workers from the local area. These challenges are strongly related to educational achievement. Educational achievement is low at primary school level and particularly at the secondary level. Given the evidence that employment rates are correlated with educational achievement, most unemployed people in the local area are likely to have low to very low educational levels. A mining operation has skill and health and safety requirements that can make it difficult to employ large numbers of people with limited education.

A second constraint is lack of job experience, and specifically mining sector job experience. Whereas the project is prepared to look at equivalencies in its recruitment, again from the available data there is little evidence of other than

agricultural and service sector employment in the local economy. There is of course some mining experience of employees of the graphite mines. Mining operations require at least a critical mass of experienced, skilled and semi-skilled employees to operate efficiently and cost effectively.

The total labour force requirements for the mine will be about 1,400 over the construction phase. Given the proponent's previous employment record during the exploration phase, and given that there will also be some semi-skilled and skilled positions that may be taken up by previous employees who gained skills during this project phase, it is predicted that over 500 workers could be sourced locally. Recruitment activities would be centred in Moramanga to offset the potential for migration to the mine site.

The total workforce requirement for the operations phase is estimated at 390. Many of the management, professional and supervisor positions will be filled by out-of-area people, at least in the earlier phases of the project. There is potential for local employment of skilled and semi-skilled, office workers, technicians, heavy equipment operators and trades people, and many will have had project supported training. About 360 jobs are predicted to be filled locally after training, largely from the labour pool in Moramanga. The potential impacts of direct employment will take some time to be fully realized, but overall are considered to be of medium magnitude, positive, long term, and of moderate consequence, although of high consequence for those individuals and their families who are able to directly benefit.

Business

Detailed procurement lists and potential sources of supply are being finalized for the mine site area. It is not expected that there will be many or large goods and service supply contracts in the mine site area. Overall, existing businesses tend to be small and with few exceptions are oriented to serving the consumption needs of local residents and tourists.

The proponent has worked successfully with some local businesses over the exploration phase of the project. Similar to employment, however, local business participation in the project is expected to grow with time, particularly with the implementation of measures to assist that participation.

The potential impacts of business opportunities will take some time to be fully realized, but overall are considered to be of medium magnitude, positive, long term, and of moderate consequence given the size of the local economy, although of high consequence for those individuals and their families who are able to directly benefit.

Local Economy

Total construction expenditures at the mine site are expected to reach \$US 150 million. Total operational expenditures are expected to be in the order of \$US 7 million per year over the 27 year operations phase. Closure and post-closure activities will also require local expenditure. Therefore the total inflow of expenditures on local wages, goods, and services could be in the order of approximately \$US 340 million over the life of the project. There are no estimates of the size of the economy in the Moramanga area, however it is likely that an injection of expenditures in the above amounts will be of high positive consequence.

Patterns of expenditure will vary over the life of the project, for example, during construction there are more large, one-time capital expenditures. Capital equipment for the mining operation will not be sourced locally. This will put downward pressure on the percentage of total expenditures being in the local area. Over time however, with increasing local experience with the project, training programs and other assistance intended to facilitate access to local populations to economic opportunities, percentages of local employment and procurement would increase.

In addition to direct employment and business opportunities, the project will be the stimulus for indirect and induced employment and business opportunities. Businesses contracted to supply the project will require new employees, and with increasing direct and indirect local economic activity, individuals and business will spend more on local goods and services. This in turn will induce more employment, and perhaps more small businesses as people in the community organize to provide additional goods and services demanded by others with new disposable income. Additional income could be spent on such items as renovations to housing, new household appliances, and vehicles (with attendant maintenance costs), further stimulating job and business creation. The project is predicted to cause the creation of 2,200 local indirect and 590 local induced jobs during mine construction and 340 local indirect and 150 local induced jobs during mine operations.

Anticipated project expenditures are expected to be comparatively large relative to the size of the local economy, the impact is considered to be of high magnitude, positive, long term, and of moderate to high consequence.

Education and Training

It is Ambatovy Project policy, and has been the practice over the exploration phase of the project, to provide on-the-job training to employees. Such training

will continue through the project life cycle, and is intended to improve skills needed for better job performance and to broaden the skill base of employees so that their enhanced abilities can be applied elsewhere in the economy. Training in heavy equipment operation and maintenance, accounting and clerical work, construction trades (electrical, plumbing, mechanical, framing, carpentry), catering, environmental studies, health and safety, computers and information technology, is transferable to other employment sectors, even if provided in a mining sector context.

The project will develop a formal training program for employees, to include skills upgrading, apprenticeship training and the establishment of entry-level positions with a view to advancing people beyond entry level on a regular interval. As the project moves forward, employees and suppliers are also expected to gain valuable experience that will position them to increase their level of participation. To the extent that this training program uses local educational institutions the quality of skills training in the Moramanga area is expected to improve.

Beyond employee training, the project also expects to address the need for a broader-based education and training strategy to provide assistance to those who wish to develop skills that could position them for employment and/or supply of goods and services at levels beyond those they would otherwise be qualified for, both with the project and in the broader economy. Elements of this strategy will include training to businesses and enabling and motivating youth to stay in high school and pursue higher education.

The potential impacts of education and training to the labour force, businesses and to the young are considered to be of medium to high magnitude, positive, long term, and of moderate to high consequence, although of high consequence for those individuals and their families who are able to directly benefit.

Commune Government Budgets

Legislation in Madagascar provides for a portion of royalties paid in relation to mining projects to be directed to communes within which mineral resources lie, in addition to a portion going to each of the provincial and to the national governments. Such legislation in international experience is put in place in the context of mining activity being largely labour intensive and small scale, with the result that royalty payments are not large.

In the case of the Ambatovy Project the large scale of the mine means that annual royalty payments will be very large in relation to existing commune revenue flows. Selected very large commune budgets – in a regional context of

neighbouring communes having very little revenue – has potential to set up inequities. Also, the project footprint is much more extensive than the mine site area, extending along the pipeline route and at the site of the tailings and plant facilities. These other areas, although far from the ore bodies, will experience project effects that royalty distribution is intended to help address.

The proponents would expect to work with the Government of Madagascar to establish an equitable system for distribution of royalties paid by the project. It is expected that resources available to communes will increase. It was noted in the baseline studies that despite the development of commune development plans, the implementation of commune priorities is constrained by a lack of resources, both financial and technical. To the extent that increased revenues enable communes to implement priorities for economic and social development, this is a project benefit. The proponents' assistance with community development and capacity building will also enhance the ability of communes to implement development priorities.

The potential effect of increased commune revenue is considered to be of high magnitude, positive, long term and of high consequence.

Increased Income

Direct, indirect, and induced employment and business creation associated with the project will increase the income levels of individuals and their families, and of the communes as a whole.

There will also be additional (indirect) earnings as a result of the business opportunities the project creates. As well, increased income is the stimulus for the induced economic activity, and therefore not only the individual project employees and the employees of contracted businesses will benefit, but others in the community will see earnings rise, further increasing the total wages paid in the community.

Increased income is generally associated, overall, with improved individual and household socioeconomic status. It is this association that appears to motivate the great emphasis given to employment, in consultations, by people and their representatives in government. The economic strategies of all levels of government are based on the creation of new economic opportunities. There is, as a major benefit of the project, potential for improved quality of life for those individuals (and their families) who are able to find employment with the project, with businesses that supply the project, or elsewhere in the growing local economy. A critical mass of improved household and business prosperity will in turn benefit the local economy.

Income can also cause negative effects at the individual, household, and community levels if that income is not well managed. Income that is not spent wisely will not generate quality-of-life improvements.

The potential impacts of increased income are considered to be of moderate to high magnitude, largely positive, long term, and of moderate consequence overall but high to those individuals and their families who are able to benefit.

Migration

The economic opportunity a large project such as the Ambatovy Project represents has potential to attract large numbers of migrants. Existing trends of rural urban migration, tensions over land in rural communes and the shortage of housing in Moramanga suggest that additional migration as a result of the project could be difficult to manage. The project will develop recruitment policies to discourage migration, and advertise these aggressively. The project will provide accommodation, meals, services and transport to and from their points of hire for most out of country workers during construction and operations, and will therefore not generally move workers or from overseas into communes. However, some senior staff will reside with their families outside of the minesite.

However people from families resident in the area local to the mine site will return in the hope of employment at home and/or other people will move to the area seeking jobs. Many people in Madagascar are experiencing economic stresses and high unemployment rates and are prepared to move on speculation of economic opportunity. Migration into the mine site area has the potential to generate negative impacts on families, the local economy, and social organization, depending on the numbers, skill sets, behaviours, employment expectations, and family status of migrants. Many of these potential effects are addressed in subsequent sections below.

On the positive side, the return of family members, particularly those who left only to find employment elsewhere, can be of great benefit to family welfare, and will be encouraged by the preferential hiring policies of the project. In-migration of entrepreneurial individuals may enhance the economic response to the project in the local economy.

Migration decisions are individual and reflect what people believe to be in their best interests under specific sets of individual circumstance. Predicting who will migrate, in what numbers, and with what net effect is therefore difficult. As such, the potential impacts of migration are complex and are likely to have both positive and negative components, but to be of moderate magnitude, long term and of moderate consequence.

Tourism

There is some concern that the presence of the mine will have biological, physical, disturbance and/or visual effects that will in turn present a negative effect on tourism. There is dependence of the commune of Andasibe in particular on tourism as a source of livelihoods. It is not only existing tourism, but also the potential to expand tourist activity into the Torotorofotsy for example, that is of concern. The environmental sections of the EA have addressed environmental impacts, and overall conclude that with proposed mitigation there is no expectation of high magnitude effects to natural resources in potential tourist sites, and with an extensive monitoring program, any unanticipated effects can be captured early and then effectively addressed. Long-term benefits may in fact be realized for the tourist industry through shared project infrastructure such as an access route along the water and slurry pipelines, or left behind after closure. The presence of expatriate workers and the general economic boost expected may in fact increase tourist receipts and provide a context for profitable investments in tourist infrastructure that would be attractive to more tourists from elsewhere in Madagascar and the rest of the world.

The effects on tourism are expected overall to be positive, of medium magnitude and long term, and therefore of moderate consequence.

5.1.3.2 Access to Natural Resources

Land

The project will require approximately 18 km² of land and rights of way for the development of the ore body and associated project infrastructure. As shown by the land use EA (Volume B, Section 5.3), most of the land within the mine footprint appears to be little used by surrounding populations. The expansion of agricultural land tends to follow river valleys and the forest remains essentially undisturbed. Also, with the exception of households to the south and east of the ore bodies (see the Resettlement Action Plan), populations live at some distance and focus their land use on areas closer to their homes. The poor soils over the ore bodies, the prohibition on tavy and distribution of population suggest that the development of the mine will not take land out of potential future agricultural use. Population growth is comparatively low in the area and there is evidence of much out migration of younger adults limiting the potential for agricultural expansion into the mine footprint. Although there is demand for more land in the communes around the mine site, and there are conflicts over land, neither of these occur in relation to land within the project footprint.

Project infrastructure land disturbances and requirements for rights-of-way (for roads, water and slurry pipelines and powerlines) have more potential to

negatively effect agricultural livelihoods in so far as they follow the roads and river valleys where people are presently engaged in agriculture. Depending on the severity of the interference with livelihood resources, people will either be physically resettled, or fairly compensated (taking into account the long-term value of assets to livelihoods), as described in the Resettlement Action Plan. As of November 2005, two households are in need of re-settlement and compensation is being evaluated for an additional 35 households.

With the exception of agricultural land that is taken out of production as addressed in the Resettlement Action Plan, the potential impacts on land resources is negative, of moderate magnitude, and long term but of low consequence.

Water

Residents within the six watersheds affected by the mine depend on river water for agriculture, drinking water, livestock watering and domestic use. Potential changes to water quality and quantity have the potential to affect livelihoods and human health.

Although the Mangoro River is a source of water for the ore processing plant at the mine, the river flows are so large including during the dry season that mine water requirements are expected to have a negligible effect on stream flow (Volume B, Section 3.8). The six watersheds at the mine site are predicted to have increases in surface water quantity. Predicted increases in flows become high after year four of operations, and have been assessed to be of potentially moderate magnitude up to 5 km downstream. This impact will be minimized through operational controls to best mimic baseline flows.

The effects on livelihoods of surface water quantity increases will vary over time, contingent on timing and amounts of rainfall events as these relate to agricultural activities in rice fields. Rice farmers experience problems with not only with water shortages but also periodic excesses of water, neither of which they have the infrastructure to manage. Adaptive management and ongoing consultation will be important during operations.

Surface water quality assessments met World Health Organization (WHO) drinking water standards and the human health impact assessment concludes that health related risks of drinking project affected water and eating crops are low to negligible. The water quality assessment predicted increases to often already high concentrations particularly of chromium, and the human health assessment concludes that this may represent a high health risk of eating fish (an important part of the local diet (see Volume K, Appendix 1.1)), including in three

watersheds extending about 5 km downstream from the mine site. It was noted that very conservative model assumptions were used and that monitoring of water quality, shall take place to ensure safe levels or to take the necessary corrective actions.

Effects of the mine on groundwater are expected to be of low consequence, and this effect is also of very limited spatial extent. It is noted that the groundwater and surface water interact together reducing high surface flows.

Construction activity has the potential to affect water quality, primarily through erosion. Such effects will be minimized through the use of construction best practice, and are likely to be short term in any case, but may represent a nuisance value to water users.

Based on issues raised during consultations about water quantity and quality it is likely that people will attribute any water-related difficulties to the project. The results of the proposed water quality and flow monitoring (as described in Volume B, Sections 3.8 and 3.9) will be communicated to people in the area to demonstrate performance and discuss any issues. This will not only provide more information, on the basis of which mitigation can be improved, but also provide the data necessary to adequately address grievances about water. Water users with valid grievances will be compensated. In addition, the proponent will participate in implementing measures to improve water management for farmers in the area around the mine.

The impacts on the quality and quantity of water resources are considered to be negative, of moderate magnitude, long term and low consequence overall taking into account the intent to monitor, employ adaptive management and to compensate for any realized impacts. This refers primarily to people farming and taking domestic water out of the six watersheds around the mine site. Elsewhere, water effects are of low to negligible consequence.

Forests

The development of the mine site will remove forest resources, and the forest management plan may impose limits to access of additional forest land. While the azonal forest under which most of the ore body lies does not appear to be much used by local populations, the transitional and zonal forests potentially affected by the project and the proposed forest management plan are more used. Use is as grazing land, as a source of artisanal and house building materials, for harvesting of both biological and aquatic food and health resources, and for both legal and illegal harvesting of wood. The baseline data indicate that a significant

proportion of livelihoods are based on forest use, especially closer to population centres.

The complicating factor is the progressive deterioration of the biological resources in the forests that people do use more often and the consequent pressure to identify undisturbed forest to continue forest-based economic activity. There may be some resentment on the part of populations around the mine site at what are perceived to be the priorities of outsiders guiding their use of forest resources.

In acknowledgement of the economic importance of forests, the project is negotiating with government and communities a forest management plan intended to preserve and/or reintroduce integrity of forests around the mine site for both human use and for environmental reasons. This does however have the potential to limit what may be unsustainable use with regard to specific areas and/or specific forest resources, at short-term cost to some people's livelihoods.

It is also expected that individuals will discover access to forest resources denied or constrained by project activities. In the event of grievances of this nature, the project will investigate to adequately address these. Valid grievances will be compensated.

The impacts on forest resources are considered to be negative, of moderate magnitude, long term but of low consequence overall taking into account the intent to compensate fully for any realized impacts.

5.1.3.3 Social and Physical Services and Infrastructure

Demand for social and physical services and infrastructure is both increased (in so far as needs increase) and decreased (in so far as poverty constrains access) by poor socioeconomic status. Increased demands for health, policing, education, water, housing and other services and infrastructure, could occur as a result of the influx of a large number of migrants and/or of increases in disposable income following the economic boost the project is expected to cause in the mine site area.

Limiting migration to the extent possible and meeting the operational needs of the mine, including providing services to workforces and their families, with project rather than commune resources will help limit pressures for the delivery of social and physical services and infrastructure. To the extent possible, the project will ensure that its power, communications, transport, and other operational needs do not depend on local facilities, and that where such local

facilities are used (local roads, the railway) the facilities are paid for and/or maintained. Food and accommodation, recreation facilities, physical and mental health services, and other goods and services deemed necessary will be provided to the mining operation independently of what is now available in local area.

Some services and infrastructure are expected to benefit from the project, and include:

- Increased employment, business opportunities, and income will provide a measure of economic security and capacity that will contribute to employability over the long term and improved well-being of employees and their families. Education and training initiatives should have similar effects. This has potential to reduce social problems coincident with poverty, and reduce demand on some social services.
- Increased commune budgets and the project's social investment could be used to increase the quantity and quality of services and infrastructure.
- Widening and improvement of the mine access roads will benefit people using those roads, to get agricultural product out for example, and there may be opportunities related to the project's construction of water and power supply infrastructure to extend such services to people.

Positive impacts are expected to gain momentum over the project life, particularly as the employment, training and business initiatives of the project improve people's socioeconomic status and as there may be increased spending on services and infrastructure. There is potential of seeing a reverse of some of this positive impact at the time of closure. Monitoring of access to services and infrastructure will be necessary to establish trends that may need to be addressed, when they are fully understood, through additional mitigation and/or enhancement measures.

The impacts on social services and infrastructure are considered to be of medium magnitude, largely positive in the longer term, and of moderate consequence.

5.1.3.4 Well-being

Potential impacts on individual and family well-being are complex, far reaching, and unpredictable, and can spill over where large enough to affect the quality for the broader population. Well-being is intimately associated not simply with increased economic opportunity, but also public health and safety, disturbance particularly during the construction phase, socioeconomic and cultural change and availability and access to the necessities of life.

Public Health and Safety

People in the mine site area are concerned that out-of-area workers and economic migrants are a potential threat to health and safety within their communities (Volume A, Section 6). Although the project will implement best practice work force management, employees housed at camp, any new migrants, and in-transit workers associated with the project will inevitably interact in unpredictable ways with people of the mine site area. Social monitoring will be critical to determining the actual effects of the project on such public health and security issues in order to respond to any evolving negative community effects of such interactions.

Attention to the potential for increasing the incidence of HIV/AIDS is particularly critical and further emphasizes the importance of the planned enforced codes of behaviour and aggressive HIV/AIDS prevention and treatment. Increases in incidence of HIV/AIDS in turn have elsewhere contributed to increased prevalence of opportunistic communicable diseases, particularly tuberculosis. Tuberculosis often first spreads in immune depressed people, but as incidence increases it spreads to the general population.

Increased vehicle traffic, with the consequent potential for more road accidents, also represents a risk to public health (Volume B, Section 5.5). The major traffic risks will come with mobilization during the construction stage as equipment is moved to site, but operations traffic will increase risk as well. Traffic risks will be minimized with clear, enforced rules for vehicle operators in combination with operator training and public education on traffic risks.

Another concern for public health and safety is the potential for project emergencies or accidents to have environmental effects, particularly on water quality. For example, a fuel or other spill could result in the release of contaminants into the food chain.

The health and safety of workers and the population at large is subject to legislation and to best practice management of hazards. The project seeks not only compliance with legal requirements but also to continually improve its safety records. Health and safety training, which will be provided to all staff, also has applications in personal life – as workers often apply new health and safety training received on the job to daily tasks conducted at home.

Worker management, operational procedures, traffic, health and safety, public education, health programming and other relevant best practices will be implemented and enforced by the project to reduce risks to public health and

security. The potential impacts of the project in this regard are therefore negative, although with successful mitigation of low magnitude.

Social and Cultural Values and Integrity

The social, cultural, and economic importance of more traditional ways of life is fundamental to well-being. Social and cultural values confirm the identity of a people and are increasingly understood as essential for social and emotional well-being, at individual, household and community levels.

The extent to which social and cultural values and integrity have and can be maintained over time depends on many variables, few of which can be attributable to any specific project. The mine is not the only event of note in the project area. Demographics appear to be shifting in response to land pressures. Tavy practices have recently been prohibited and that prohibition enforced. There is a perception that climate has been changing, forcing changes in agricultural calendars. Forestry as an industrial activity has declined, and this in combination with rural urban migration has changed the nature of the Moramanga economy. Economic, social and environmental change has been ongoing, bringing social conflict, increased economic stress, competition for resources and other impacts, some of which are similar to those that may be generated by the mine.

Some social erosion has been observed, largely in response to in and out migration, economic stress, increased communications, general economic transition into a service economy, and the associated social and cultural transition. The project has the potential to be an additional force of change to social and cultural values and integrity.

Maintaining social and cultural values and integrity can be challenging in the context of a large mining project with some imported workforces, well paid employees and possible induced migration. Cross-cultural contact will increase as the project moves forward - employees and businesses will function within the project's corporate culture, policies, and operational requirements and transport of people and materials through local communities will occur. Higher incomes will bring family and public behaviour changes.

The project will put in place human resource policies and procedures designed to address some of these concerns to the extent possible, including worker codes of conduct, cross cultural training and establishment of workplace conditions that are sensitive to local ways of life. In combination with other ongoing processes, participation in the project may contribute to erosion of social values and

integrity. The project effect would be considered of medium magnitude, long term and medium consequence.

Disturbances

Project construction will produce temporary impacts on air quality, in so far as clearing of land, earth movement, transport of equipment and supplies, and building of infrastructure will generate dust and air emissions. Noise associated with transportation, including road traffic can be a disturbance. Increased traffic represents a source of pollution, a potential source of spills, a health and safety hazard, and an irritant. Large construction sites can be visually unappealing.

Dust, noise, and visual disturbance experienced by residents will be primarily in relation to any construction-related activities (primarily traffic, but also construction of associated project infrastructure) in the communities themselves rather than at the mine site. Transportation activities, with associated disturbances, will be ongoing throughout the project life.

All construction and transportation activities will be conducted according to best practice to minimize disturbances. Planned traffic mitigation is discussed in Volume B, Section 5.5.

The project's potential disturbance impacts are considered negative. Most disturbances will be of low magnitude and short term, as they will occur primarily during the construction phase and only intermittently after that. Overall significance is therefore considered low.

5.1.3.5 Closure

The planned closure phase of the project may extend over five years as physical plant and other infrastructure is removed and reclamation activities are completed (Volume B, Section 6). During this phase, expenditures for labour, goods, and services will be much lower than during the operations phase. At the end of the closure period, all expenditures – with the possible exception of limited employment related to monitoring during post closure – will come to an end. Royalty payments and the social investment spending will also come to an end with mine closure.

Closure has the potential to cause economic and associated social dislocation. The closure of a major project inevitably involves unemployment and contraction of business, with consequent social problems at the individual, family, and community levels. The proponents intend to begin preparing for closure at the earliest stages of project development. Sustainable development principles will

be integrated into all mitigation and benefit enhancement measures – both those implemented by the project as regular best operational practices, including for example, measures that will be put in place to enhance employment and business capacity in the broader economy. Additionally however, increased commune government budgets and the project's partnerships in community development planning are expected to improve the quality of life of people local to the project, positioning them to achieve improved socioeconomic status over the life of the project and thus improved capacity to absorb the change following closure.

With thorough planning and consultation, the reversal of economic and social benefits inherent in the closure of the Ambatovy Project is considered to be a negative impact of moderate magnitude, long term and of moderate consequence.

5.1.3.6 Summary

The socioeconomic impacts of the project, as described in this section, are summarized in the socioeconomic impact matrix in Table 5.1-2. The table includes an assessment of potential impacts before and after proposed mitigation, and presents alternative scenarios for certain impacts that could eventually be deemed either positive or negative.

Overall, the project is expected to bring high economic benefits to the mine site area which will represent an important boost to the local economy. To the extent that there is potential for negative effect, direct mitigations and an adaptive management strategy will be put in place. The strategy includes consultation, social monitoring and a commitment to work to minimize identified negative impacts through a participatory approach with stakeholders.

Table 5.1-2 Mine Site Impact Matrix

| MINE SITE | | | | | | | | |
|---|---|--|--------------------------|-------------------|--|--|-----------------------|---|
| Dimension | Residual Impact | Geographic Extent | Phase (Duration) | Before Mitigation | | Mitigation | After Mitigation | |
| | | | | Direction | Consequence (including magnitude) | | Direction | Consequence (Including Magnitude) |
| Economic Opportunities | | | | | | | | |
| local employment | potential for an estimated 360 direct jobs during operations but increasing with time, and up to 540 jobs during construction | rural communities, Moramanga | construction, operations | positive | low in absence of preferential systems | preferential local employment and training for residents of Moramanga and nearby communes, with verified residence status | positive | high for individuals able to access project related employment opportunities and moderate at the commune level given number of jobs relative to population size |
| procurement of local goods and services | increases in business activity related to project supply contracts | Primarily Moramanga with opportunities for nearby communities increasing over time | construction, operations | positive | low in absence of preferential systems | preferential local procurement and training programs | positive | high for individuals owning or working in business that are able to access project opportunities low in rural communities and moderate in Moramanga given the existing business establishment, but increasing with time |
| indirect and induced economic growth and economic diversification | potential for indirect and induced jobs | rural communities and Moramanga | construction, operations | positive | low in absence of preferential systems | none required additional to preferential employment and procurement | positive | moderate to high |
| | inflation | rural communities and Moramanga | construction, operations | negative | moderate given size of mine relative to local economy although migration will also contribute | beyond measures to control migration no direct mitigation possible project benefits will contribute to overall community wellbeing | positive and negative | direction and consequence of effects contingent on one's position in the economy vulnerable groups are most negatively affected |
| | widening inequality of income | rural communities | construction, operations | negative | moderate | no direct mitigation possible | negative | low, given expectations that the project will build partnerships and assist with ways to increase community wellbeing and can target the needs of the poorest members of society |
| capacity building of labour force and businesses | education, training and experience for employees and businesses that can be applied to project related jobs and in the larger economy | rural communities, Moramanga | operations | positive | low in absence of preferential systems | none required additional to preferential employment, procurement and training programs | positive | high for individuals and moderate for communities |
| | improved educational achievement in the broader population | rural communities, Moramanga | operations | positive | negligible in absence of education and training strategy | education and training strategy | positive | high for individuals and otherwise low to moderate insofar as community effects are experienced |
| fiscal benefits to commune governments | increases to commune budgets as a result of royalty distribution | rural communities | operations | positive | high relative to local budgets | none required, royalty decisions dependent on government | positive | high relative to local budgets expectation is that increased revenues will increase quality of life in communities |
| increased individual income | increased employment opportunities at generally good wages | individual | construction, operations | positive | high for affected individuals | none required additional to preferential employment, procurement and training programs | positive | moderate overall, but high for individuals accessing employment there is some potential for negative effect |
| migration | in migration | rural communities and Moramanga | construction, operations | largely negative | impact contingent on who might migrate, in what numbers, with what family status and skill sets, some potential for positive effects | preferential employment locally, but recruitment activities based in Moramanga aggressive public information campaign on recruitment procedures | negative and positive | impact contingent on who might migrate, with what family status and skill set |
| tourism | environmental effects reduce the tourism value of mine site area | rural communities, specifically Andasibe, and Moramanga | construction, operations | negative | low | environmental mitigation to reduce potential environmental effects project will also potentially create market and economic context for improving tourism | positive | low to moderate |
| Natural Resources | | | | | | | | |
| availability of land resources | land use changes | rural communities | construction, operations | negative | moderate | avoidance of villages, households and agricultural land compensation where avoidance is not possible | negative | low and some people may benefit as a result of compensation |
| | land shortages and price increases | rural communities and Moramanga | construction, operations | negative | moderate given existing land and housing shortages | beyond measures to control migration no direct mitigation possible | negative | low |
| | reduced land availability for expansion of agricultural lands | rural communities | construction, operations | negative | low given geomorphology and soils of mine site | no direct mitigation possible | negative or positive | low negative however some potential for moderate benefit should agricultural productivity be selected in consultations as a priority area for intervention; project could assist with the enhancement of agricultural productivity and therefore reducing pressure on land resources |

Table 5.1-2 Mine Site Impact Matrix (continued)

| MINE SITE | | | | | | | | |
|--|--|----------------------------------|--------------------------|-------------------|--|---|----------------------|--|
| Dimension | Residual Impact | Geographic Extent | Phase (Duration) | Before Mitigation | | Mitigation | After Mitigation | |
| | | | | Direction | Consequence (including magnitude) | | Direction | Consequence (Including Magnitude) |
| | disputes and changes to land tenure systems | rural communities | construction, operations | negative | low given most project affected land is not presently affected by conflicts | no direct mitigation possible | negative | low |
| effects on water resources | reduced or increased water availability for agriculture as a result of potential environmental effects and project water use | individual | operations | negative | moderate given dependence on water resources from mine site area | mitigation of potential mine generated water quantity effects at source | negative or positive | low negative, and some potential for moderate benefit should water management be selected in consultations as a priority area for intervention; project could assist rural communities with water management |
| | reduced water quality for human consumption and agriculture as a result of potential environmental effects | rural communities and individual | operations | negative | low given distance of populated areas relative to project | mitigation of potential mine generated water quality effects at source sustainable compensation for residual effects | negative or positive | low negative and some potential for moderate benefit should potable water be selected in consultations as a priority area for intervention |
| effects on availability of forest resources | reduced access to forest resources used for livelihood purposes | rural communities and individual | construction, operations | negative | moderate to high, given the dependence on forest resources as a supplement to other livelihood resources | forest management planning in consultation with communities sustainable compensation for residual effects where access and/or use restrictions have economic consequences | negative to positive | low negative with some potential for moderate to high benefit in long term as improved forest management should allow sustainable use over time |
| Social and Physical Services and Infrastructure | | | | | | | | |
| social services | population increases and increase in disposable income result in increased demand for the full range of social services | rural communities and Moramanga | construction, operations | negative | impact contingent on population increase and choices with regard to expenditure of new disposable income | measures to control migration project workforces will be provided with health services | negative to positive | moderate negative to moderate positive depending on social service affected and how demand evolves |
| | improved quality of service delivery | rural communities and Moramanga | construction, operations | positive | low | increased government revenue and planning to improve health and education service delivery | positive | moderate to high contingent on decisions with respect to commune budgets and any additional support provided by the project |
| infrastructure | housing pressures in Moramanga as a result of migration | Moramanga | construction, operations | negative | moderate | measures to control migration | negative | moderate, given that despite mitigation measures combination of project and existing rural urban mitigation will continue to put pressure on housing |
| | infrastructure built and/or improved | rural communities and Moramanga | construction, operations | positive | low | access to infrastructure built or improved for project purposes and infrastructure built taking into account any opportunities for public use | positive | moderate |
| Community Wellbeing | | | | | | | | |
| public safety | increase in anti social public behaviours | rural communities and Moramanga | construction, operations | negative | moderate | workforce management through cross cultural training and enforced codes of conduct work with authorities to assist with public security and contribute to overall community wellbeing incompensation for any residual negative effects | negative | low |
| public health | increase in HIV/AIDS and other transmissible diseases | rural communities and Moramanga | construction, operations | negative | high | project workforces will be provided with health services community and workforce HIV/AIDS programming | negative | low although there is some long term potential for benefit as a result of aggressive HIV/AIDS programming |
| increased risk to public health and safety due to construction and operations activities | risks associated with traffic, including transport of hazardous materials and accidents | rural communities and Moramanga | construction, operations | negative | consequence of risk is high given the potential harm that any such accident has the potential to cause | full range of best practice operations to limit all effects of increased traffic | negative | mitigation is expected to reduce risk considerably |
| | water quality effects on public health | rural communities and Moramanga | construction, operations | negative | moderate | full mitigation and range of best practice to limit water quality effects | negative | negligible to low contingent on actual affect of water quality of fish |
| | noise effects on public health | rural communities and Moramanga | construction, operations | negative | negligible as traffic noise does not represent a threat to public health, although disturbance can occur | full mitigation and range of best practice to limit effects of noise | negative | negligible as traffic noise does not represent a threat to public health, although disturbance can occur |
| | air quality effects on public health | rural communities and Moramanga | construction, operations | negative | low as with the possible exception of traffic, project emissions are far from population | full mitigation and range of best practice to limit effects on air quality | negative | negligible |

Table 5.1-2 Mine Site Impact Matrix (continued)

| MINE SITE | | | | | | | | |
|--|---|---------------------------------|--------------------------|-------------------|---|--|------------------|---|
| Dimension | Residual Impact | Geographic Extent | Phase (Duration) | Before Mitigation | | Mitigation | After Mitigation | |
| | | | | Direction | Consequence (including magnitude) | | Direction | Consequence (Including Magnitude) |
| social and cultural changes | economic, social and cultural transformation | rural communities | construction, operations | negative | low to moderate, taking to account the degree to which rural ways of life are already under some stress and undergoing change | no direct mitigation possible project benefits | negative | medium consequence but needs to be set beside benefits to socioeconomic status which can only be achieved at some cost to prevailing culture, irrespective of source of benefit |
| disturbances | disturbances to quality of life (including economic activity dependent on road use) elements such as visual, traffic, noise changes | rural communities and Moramanga | construction, operations | negative | moderate given existing levels of traffic reported | full mitigation and range of best practice to limit effects on quality of life elements | negative | low |
| | perceptions of harm as a result of the project | rural communities and Moramanga | construction, operations | negative | moderate | workforce health and safety training, public education on actual risks of harm as a result of the project, emergency response planning | negative | low |
| improved community wellbeing | economic and community development and capacity building | rural communities and Moramanga | operations | positive | not applicable as this is purely a project benefit | not needed, project benefit over and above mitigation | positive | high; project's involvement in planning and capacity contributes to overall community wellbeing royalty distribution may also contribute to service improvement |
| | support to regional planning | rural communities and Moramanga | operations | positive | not applicable as this is purely a project benefit | not needed, project benefit over and above mitigation | positive | high; participation in planning initiatives and support to regional planning; other project mitigation measures to consider complementarily with regional and commune plans |
| Closure | | | | | | | | |
| closure and consequent economic and social effects | end of economic opportunities | rural communities and Moramanga | closure | negative | high | planning for eventual mine closure through participating in discussions on initiatives towards sustainability consultative and iterative mine closure planning will include consideration of employee future | negative | moderate |

5.2 CULTURAL PROPERTY

5.2.1 Introduction

This section presents the Environmental Assessment for the effects of the mine on cultural resources, as per the Ambatovy Project (the project) Terms of Reference.

5.2.2 Study Area

The mine Local Study Area (LSA) used for the cultural property impact assessment comprises the footprint area of the mine (Volume A, Section 7, Figure 7.2-1). Some cultural resources have been identified outside of the current footprint area, and are included in this study for the sake of completeness.

5.2.3 Baseline Summary

The following provides a summary of the results of cultural resources studies that have been conducted within the LSA. 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 Ambatovy between April and May 2004. 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 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 |

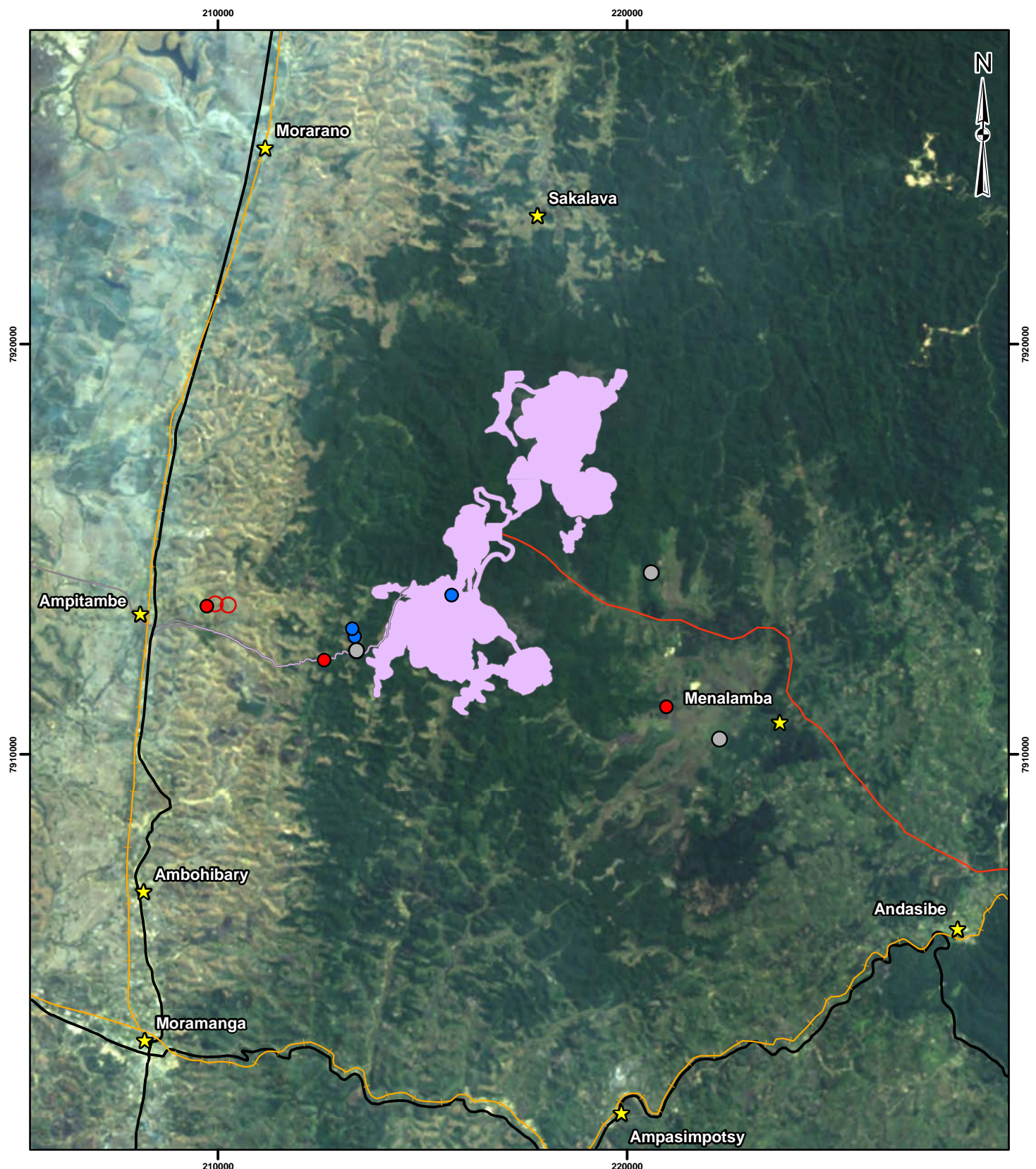
The general development area has been settled at least since the 18th century with populations who have based their livelihoods on rice and livestock, focusing on slash and burn (Tavy) agriculture. This type of agriculture, combined with a preference for small villages rather than isolated houses, results in the fact that villages are periodically partially or completely abandoned as people move closer to new lands.

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 minesite area, three sacred waterfalls, three ceremonial centres, two symbolic tombs, and several ancient villages were located (see Figure 5.2-1). Of these cultural resources, however, only one sacred waterfall is located within the actual minesite boundary. In addition, about eight kilometres east of the Ambatovy ore body, a hill named Ambavahadivohitra has been identified as being a principal cult (fisokona) area, used by the regional population as a whole.

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LEGEND

- | | | | |
|---|---------------------|---|----------------|
| ● | ARCHAEOLOGICAL SITE | — | RAILROAD |
| ● | CEREMONIAL SITE | — | ROAD |
| ● | SACRED WATERFALL | ■ | MINE FOOTPRINT |
| ○ | SYMBOLIC TOMB | | |
| ★ | POPULATION CENTRE | | |
| — | SLURRY PIPELINE | | |

REFERENCE

Landsat 7 Mosaic Image; Captured April/Sept. 2001
Datum: WGS 84 Projection: UTM Zone 39S



| | | | | |
|---|--|---|----|----------------|
| PROJECT | | AMBATOVY PROJECT | | |
| TITLE | | VIEW OF MINE SITE AND LOCATIONS OF ARCHAEOLOGICAL AND CULTURAL SITES | | |
|  Golder Associates Calgary, Alberta | | PROJECT No. 03-1322-172 | | SCALE AS SHOWN |
| | | DESIGN | LB | 13 Sep. 2005 |
| | | GIS | LL | 25 Oct. 2005 |
| | | CHECK | GJ | 09 Feb. 2006 |
| | | REVIEW | DM | 09 Feb. 2006 |
| FIGURE: 5.2-1 | | | | |

Overall, it is thought that there is a relative scarcity of sites in the mine site area because the relief and soil type over the ore bodies are not favourable to agriculture. Until now, people have not been dependent on the relatively poor forest resources in the azonal forest, but have rather focused on the biologically richer zonal forests further away from the mine site.

5.2.4 Issue Scoping

A main concern raised consistently during public consultation, is that tombs should not be disturbed. Also, if they must be disturbed, compensation should be negotiated and the movement needs to be handled in a culturally appropriate way (Volume A, Section 6). The main potential issues relating to cultural resources are:

- destruction of cultural sites during mine site construction (primary impacts); and
- disturbance of nearby cultural sites during and after mine site operation (secondary and tertiary impacts).

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.

Potential secondary impacts relating to hydrologic or soil erosion effects off of the project footprint were evaluated based on impacts predicted in the hydrology and soils EA sections (Volume B, 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.

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 mine site footprint regional: effect extends beyond the mine site footprint (secondary impact) | 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 disinvestment of sacred nature of waterfall | neutral magnitude, but permanent and irreversible effects |
| operations | increased presence of non-local workers in the region off-site hydrologic and erosion impacts | cultural sensitivity training maintenance of hydrologic regimes; erosion control along access corridor | potential moderate magnitude, medium-term and reversible effects on cultural resources adjacent to mine site none |
| closure | none | none | none |

5.2.5.4 Mitigation

Although the sacred waterfall in the mine area cannot be relocated, its sacred aspect can be modified. This is accomplished by virtue of the people's loss of contact with it – if rituals cannot be conducted there, it is no longer considered sacred by them. Such cases are common in Madagascar, occurring for example, in areas of urban expansion. 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.

Any resettlement that may 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 be mitigated by maintenance of hydrologic regimes, as described in Volume B, Section 3.8, and by erosion control along the sides of the mine access corridor.

Tertiary impacts will be mitigated through educating non-locals of the local cultural practices and by ensuring that non-local workers avoid visiting cultural resource sites adjacent to the direct impact zone of the development.

5.2.5.5 Conclusions

Following mitigation, the mine will have a neutral effect on cultural resources during the construction phase, because the sacred waterfall located therein may be moved without altering its inherent cultural meaning.

No secondary effects due to off-site hydrologic or erosion impacts are anticipated.

A potential moderate medium-term effect on cultural resources adjacent to the mine site may occur during the operations phase, depending on whether the non-local residents working on the mine site will come into contact with these.

No effects are envisioned for the mine closure phase.

5.3 LAND USE

5.3.1 Introduction

This section presents the Environmental Assessment (EA) for the effects of the mine on land use. As per the Ambatovy Project (the project) terms of reference, land use has been mapped in the mine 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 B, Section 5.1.

5.3.2 Study Area

The mine land use LSA is the same as the terrestrial LSA shown in Volume A, Section 7.2, Figure 7.2-1. This area includes the Ambatovy and Analamay mine footprint areas, the Torotorofotsy Wetlands, and the corridor for the Mangoro water intake pipeline and mine access road.

5.3.3 Baseline Summary

Lands in the LSA include intact and degraded zonal forest, intact and degraded azonal forests and scrublands, areas of herbaceous vegetation, eucalyptus plantations, woodlots, rice paddies and villages (Volume K, Appendix 3.1, Section 3.3). In the immediate area of the mine site, the most prominent land use activity since 1960 has been mining exploration. In the surrounding areas, lands are largely forested, providing opportunities for small-scale forestry and gathering of non-timber forest products. Along the water intake corridor from the Mangoro River, the predominant land uses are woodlots, plantations, rice paddies and grazing areas; several villages are located within this corridor. In the area of the Torotorofotsy Wetlands, which has been declared a Ramsar site (Volume B, Section 4.5), there is also land use activity, including rice paddies, woodlots and plantations.

Under baseline conditions, land use within the LSA is gradually transforming the vegetation cover of the landscape. It is estimated that the current rate of deforestation (removal of primary forest and increases in degraded forest, cleared areas and plantations) is about 1% per year. Additional details concerning regional deforestation rates are provided in Volume K, Section 3.1.

5.3.4 Issue Scoping

Key issues raised by the public relating to land use during public consultations include:

- degradation of forest lands, including loss of economic timber resources;
- deterioration of rice growing areas;
- sedimentation of rivers, affecting water use and agriculture;
- changes to hydrology (water volumes, especially in rice growing areas);
- in-migration of others into the area and subsequent land use conflicts; and
- will reclaimed lands be usable and will pit areas left after mining will be filled.

5.3.5 Assessment Methods

Two cases are considered for land use: a base case, assuming no project occurs, and a project case under which specific impacts will occur on land use. Land use changes under the base case are considered under an extrapolation of existing land use trends. Land use changes under the project case are considered through a spatial analysis of the kinds of land use areas that will be altered or made inaccessible by the project.

The effects of land use impacts are social in nature and are addressed within the impact rating system in the socioeconomics section (Volume B, Section 5.1).

5.3.6 Impact Assessment

5.3.6.1 Base Case

Based on the existing activities in the mine LSA, and historical trends, it is important to consider that without mining activity, deforestation is likely to continue at a rate of about 1% per year in areas not physically protected from land use activity. Over the same time span that the project is projected to last (30 years), 26% of the primary forest in the LSA would be converted. At the same time, however, under the future base (no project) case, the local populations would have the opportunity to use and access lands that will be made inaccessible by mine operations.

Areas protected from land use activity in the future under the base case (for example, by enforcement of protected area status of the Torotorofotsy Ramsar site or Mantadia-Zahamena Conservation Area) will also be lost to local populations as sources of land for some kinds of land use, depending on the degree of protection.

5.3.6.2 Project Case

A linkage diagram for land use is presented in Volume H, Appendix 9. Potential impact pathways between the mine and changes in land use exist for:

- alteration of soils, terrain and vegetation;
- decrease in availability of land for certain uses within managed buffer zones;
- changes in hydrology (water flow);
- changes in fish habitats and abundance;
- changes in wildlife populations and/or distribution; and
- increased population pressure.

Alteration of Soils, Terrain and Vegetation

The impacts of the project on areas with a variety of potential land uses are presented in Table 5.3-1. Impact areas are mapped in Figure 5.3-1.

Within the LSA, 100% of current industrial land use areas (3 ha) will be impacted by the development, but current industrial areas consist of exploration and mine camp areas entirely related to the project, so this is not a negative impact. Three percent (82 ha) of herbaceous grasslands in the LSA will be impacted by the project. This results in a slight decline in the potential grazing lands to the west of the mine and is primarily a result of the widening of the access corridor for the water intake pipeline and main mine access road. Less than 1% (3 ha) of rice paddies in the LSA are affected, as the access corridor is routed to try and avoid these important land use areas to the maximum degree feasible. About 1% (0.3 ha) of the areas within villages identified in the LSA are affected by the project; these areas have also been avoided by the project to the maximum degree feasible. Less than 1% (19 ha) of other agricultural areas, such as tavy, are affected.

Table 5.3-1 Land Use Impact Areas for the Mine Local Study Area

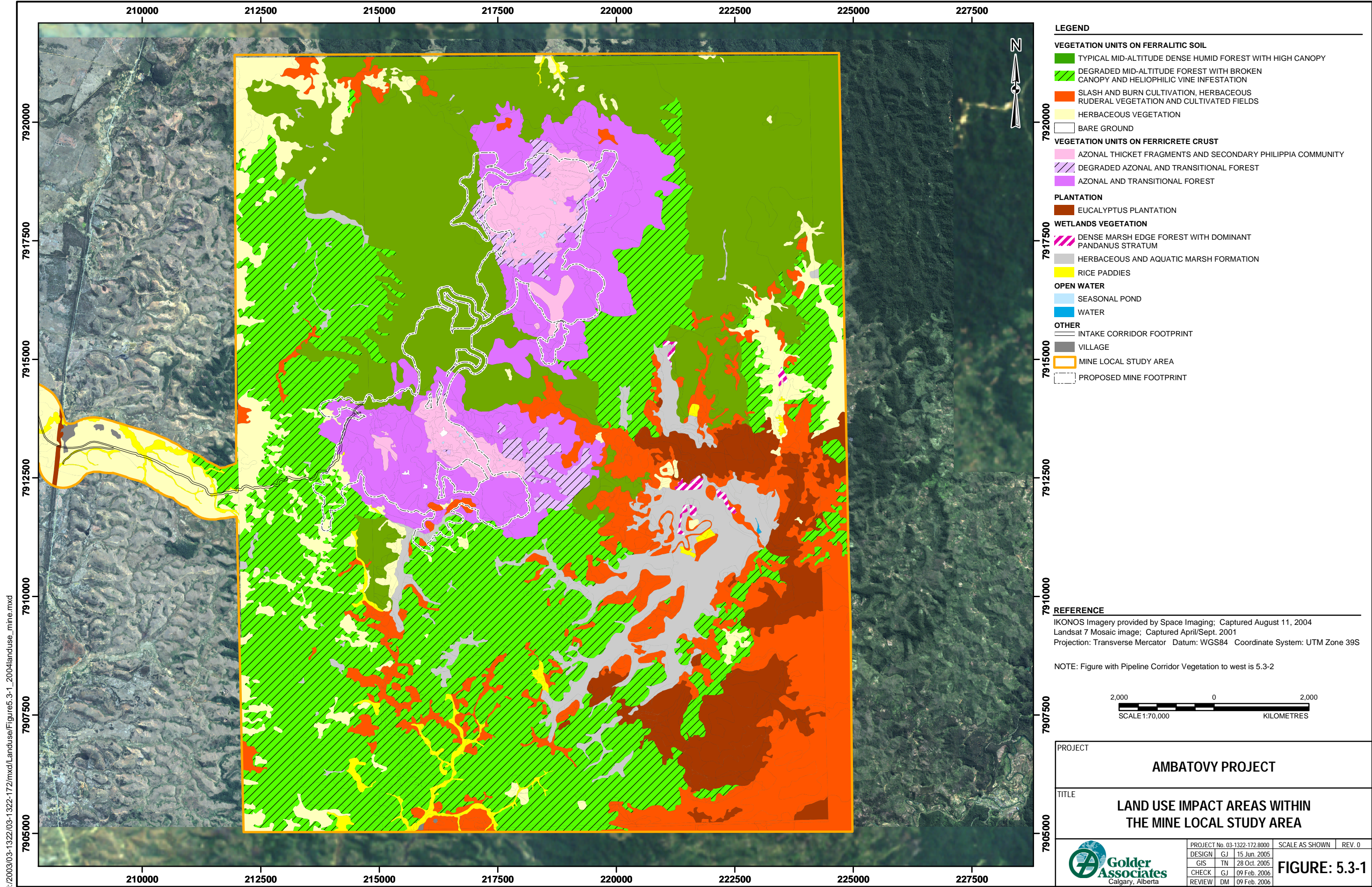
| Type of Area | Area Within LSA (Baseline) (ha) | Area Impacted (ha) | Proportion of Area in LSA Impacted (%) |
|---|---------------------------------|--------------------|--|
| degraded residual coastal woodland | 0 | 0 | 0 |
| azonal/transitional forest and scrub | 2,833 | 1,303 | 46 |
| primary zonal forest and marsh edge | 4,998 | 308 | 6 |
| degraded primary zonal forest | 6,866 | 59 | 1 |
| agroforest/secondary forest | 0 | 0 | 0 |
| plantation | 0 | 0 | 0 |
| woodlot | 1,491 | 5 | <1 |
| beach ridge complex | 0 | 0 | 0 |
| coastal shrubland/grassland complex | 0 | 0 | 0 |
| rice paddies | 283 | 3 | 1 |
| shrubland/herbaceous/pasture | 2,794 | 85 | 3 |
| tavy matrix | 2,583 | 19 | <1 |
| village/urban | 27 | 0.3 | 1 |
| wetlands | 1,114 | 12 | 1 |
| access corridor (road/rail) | 0 | 0 | 0 |
| industry (buildings or exploration areas) | 3 | 3 | 100 |
| canal | 0 | 0 | 0 |
| quarry | 0 | 0 | 0 |
| river/water | 10 | 0 | 0 |
| seasonal pond | 4 | 4 | 89 |
| totals^(b) | 23,006^(a) | 1,798 | 8 |

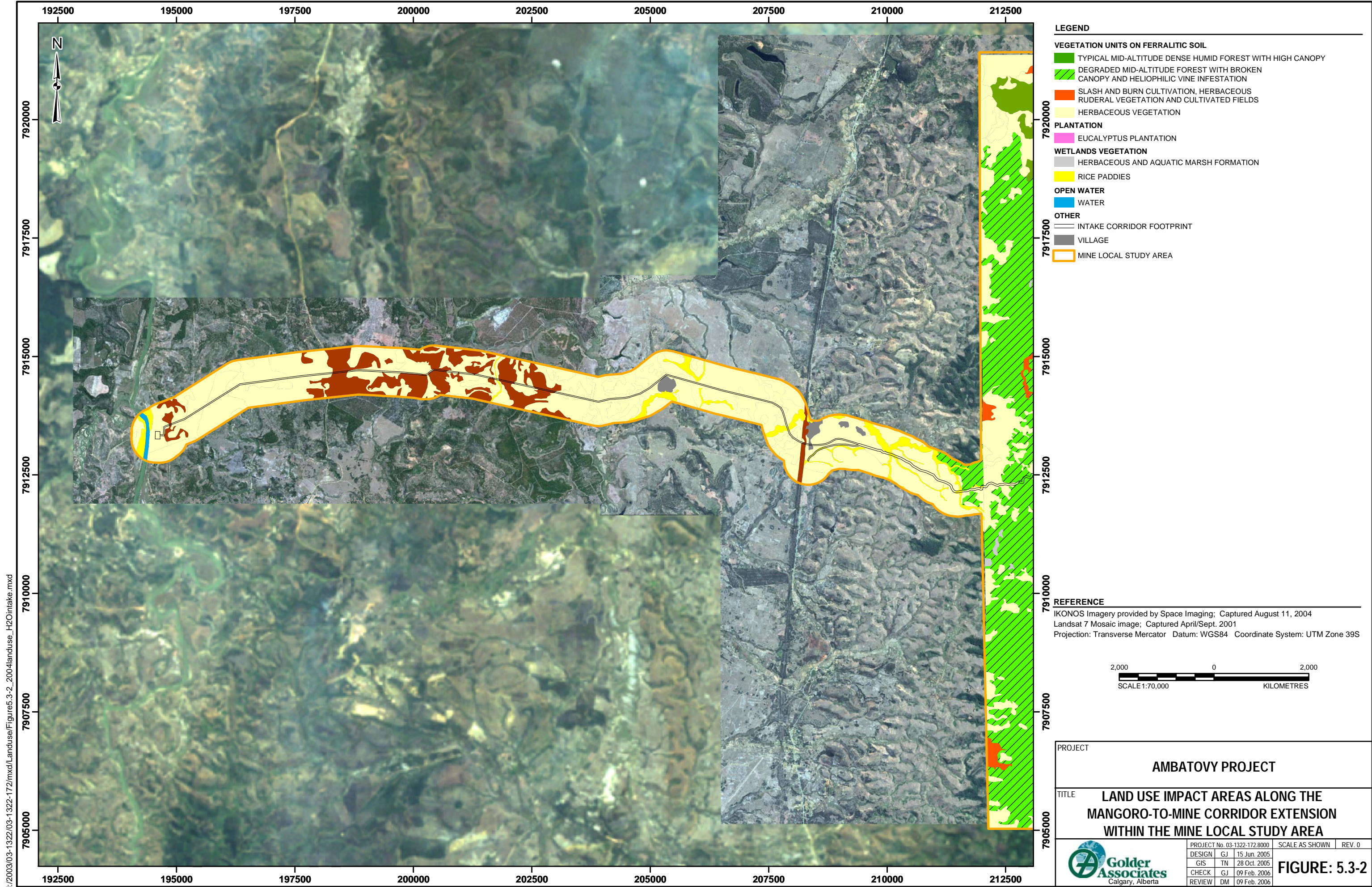
^(a) Varies slightly from terrestrial biology EA due to larger extent of area along intake pipeline corridor

^(b) May not add up as written due to rounding.

Of the areas to be impacted by the mine, many are already disturbed under baseline conditions. Exploration activities, both recent and historical, have resulted in the cleaning of 33 ha of azonal / transitional forest and scrub.

Eleven percent (1,670 ha) of forested areas (zonal, azonal and degraded) in the LSA are affected by the project. Based on forest research conducted during the exploration campaign, it was estimated that about 74 cubic metres of timber (using trees of a diameter of 10 cm or greater) can be taken from each hectare cut. Therefore, a total of 123,580 cubic metres are expected to be cut during clearing activity for the project. The market value of the trees cut vary depending on the species. Some of the most valuable species have been removed from the area, at least in part, by past forest extraction activity.





Constraints Within Buffer Zones

In addition to direct impacts of the mine, an area around the perimeter of the mine and two “azonal protection areas” being protected for purposes of biological mitigation, will be actively managed and will not be accessible for certain land use activities during the construction and operation of the project. Land use planning for these areas is part of the forest management plan presented in Volume H, Appendix 6. The effects of the loss of these areas for active land use is expected to be a small incremental addition to the impacts described above; most of the land affected is forested and not presently under heavy land use pressure.

Changes in Hydrology

If all of the mine storm water was used for ore processing, the streams flowing from the mine could be affected immediately downstream of the mine site, but less affected as distance increases downstream (Hydrology: Volume B, Section 3.8). The potential rice growing areas that could be impacted are the Antsahalava and Sahamarirana watersheds, which have areas of rice cultivation that are irrigated by streamflow along their mainstem valleys. An initial water impact analysis was conducted for a project design scenario where water within mine footprint watersheds was not allowed to return to the downstream basins. The analysis concluded that this would result in water shortfalls affecting up to 400 downstream land users (rice farmers). Rice production is already not considered sufficient in this area to meet some household needs. The analysis conducted suggested that without mitigation there may have been shortfalls in water availability relative to rice requirements in the late dry season in both mean flow years and (more seriously) in dry years extending to 10 km downstream in both the Antsahalava watershed and the Sahamarirana watershed (Volume K, Appendix 3.2).

As a result of these calculations the option to use the Mangoro River to support mine activity and allow storm water collected from the mine area to continue being released to the water basins was chosen, ensuring minimal impacts occur to rice farmers. As a result of this mitigation, a relatively natural water regime will continue within both the Antsahalava watershed and the Sahamarirana watersheds (Volume B, Section 3.8), with no negative effects on land use.

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 mine on fish and fish habitat, and effects on the artisanal fishery are described in Volume B, Section 4.3.

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 mine on wildlife due to various factors are described in Volume B, Section 4.2.

Increased Population Pressure

The project will result in the in-migration of a considerable number of people into the LSA and surrounding areas, such as Moramanga. As a result, there may be increased pressure on lands for agricultural land use and the cutting of trees for charcoal or building materials. These subjects are addressed in the socioeconomic section (Volume B, Section 5.1).

5.3.6.3 Mitigation

Much of the mitigation for land use is based on project design. The access corridor to the mine, including the corridor for the Mangoro water intake pipeline, has been routed to avoid villages and key agricultural land use areas. While the mine itself is not flexible in terms of location, it is located in an area that is presently not used to a great degree for land use activity.

Land uses outside of the project footprint have the potential to be impacted by the project, but planned mitigations will reduce such effects to very low levels. These mitigations include:

- Maintaining water volumes flowing from mine watersheds at baseline levels, including appropriate seasonal variation, through the management of collected storm water within the mine areas and using water from the Mangoro River intake pipeline for the ore processing plant (described in Hydrology, Volume B, Section 3.8).
- Maintaining and monitoring water quality for flows out of the mine area (described in Water Quality, Volume B, Section 3.9).
- Making available the viable timber by setting the timber aside.
- Development and support for a regional forest management plan that will include consideration of land use during and after the project (Volume H, Appendix 6).
- Development of other socioeconomic mitigation and compensation measures for those directly or indirectly affected by the project, as described in the socioeconomic section (Volume B, Section 5.1).

- Reclaiming mine areas following the completion of the project, to function ecologically in accordance with regional land use objectives (described in Volume B, Section 6 and Volume H, Appendix 7).

5.3.7 Conclusions

The project will have a small effect on land uses in the immediate area of the project due to direct disturbance of lands used for grazing, rice and tavy agriculture. These impacts relate to very small proportions of the land available for these purposes in the LSA, and compensation will be provided for these impacts where they occur. The project may also have indirect effects on land use in areas surrounding the mine due to alterations in air and water quality, as well as water quantity, but mitigations will largely eliminate these impacts. The greatest effects on land use may be due to increases in the local population due to in-migration resulting from real or perceived economic opportunities provided by the project. The magnitude of these impacts in socioeconomic terms is evaluated in Volume B, Section 5.1.

5.4 HUMAN AND ECOLOGICAL HEALTH

5.4.1 Introduction

The Human and Ecological Health Environmental Assessment (EA) includes an evaluation of effects of chemical emissions on humans, human ecological resources and aquatic life receptors. In evaluating the potential impacts on health resulting from activities associated with the Ambatovy Project (the project), chemical emissions from the mine were considered in combination with other existing sources and background concentrations in the environment.

The issues related to water quality are particularly important for the project given the sensitivity of this resource, its key role in natural ecosystems (such as the Torotorofotsy Wetlands), and its usage in day-to-day life in Madagascar (drinking water, watering livestock, rice paddies and fishing). Questions concerning potential health effects associated with changes in water quality and quantity were also raised during public consultation with local stakeholders on the development of the mine and are listed in the project Terms of Reference. Therefore the assessment of impacts on chemical emissions on human and ecological receptors in the mine area has a strong focus on the aquatic pathways.

Additional issues are the potential impact on air, soil and food quality that might arise from upset conditions and emissions that could affect human and ecological health as well as livelihood resources (livestock, crops and fisheries) which are also addressed here. Potential impacts on terrestrial flora and fauna health are evaluated in Section 4 (Biological Assessment) in this volume.

A brief summary of baseline assessment for the mine area is provided in Section 5.4.3 (Baseline Summary). Discussion of potential incremental effects caused by the project to human and aquatic life health are presented in Section 5.4.4 (Impact Assessment).

5.4.2 Study Areas

The human health assessment focused on the town of Moramanga and four rural communities that surround the ore body: Morarano Gare, Ambohibary, Ampasimpotsy and Andasibe (Volume A, Section 7.2, Figure 7.2-1).

The aquatic study area is based on surface water features potentially directly affected by the mine and ancillary activities. This includes the rivers, streams, ephemeral ponds, springs and wetlands within the drainages directly affected (i.e., footprint of the mine and ancillary activities) or indirectly affected

(i.e., change in downstream flow and water quality) (Volume A, Section 7.2, Figure 7.2-1).

As the ore bodies generally lay on a high plateau and a drainage divide, the headwaters of several basins originate within the ore body area. An internationally recognized Ramsar wetlands system, the Torotorofotsy Wetlands, is located immediately downstream of the mine site, and is included in the study area.

5.4.3 Baseline Summary

5.4.3.1 Introduction

Evaluation of potential impacts on water quality for the mine project required that baseline data be collected and assessed to describe background conditions and to provide context for potential impacts associated with future operations and closure.

A detailed description of the methods used for the screening-level risk assessment and its results are found in Volume K, Appendix 4.1. A short summary is provided below.

5.4.3.2 Methods and Main Results

Human Health

The human health assessment focused on ingestion of drinking water and fish. The potential risks to critical receptors, i.e., a child (toddler life phase, from seven months to four years of age) and a “composite” receptor (a hypothetical receptor which experiences exposure for the first thirty years) were evaluated. Arsenic, cadmium and nickel were considered chemicals of potential concern under baseline conditions.

Levels of fish tissue met recommended values for fish consumption suggesting that their ingestion as a regular food resource by people is unlikely to cause health effects.

Non-carcinogenic risks associated with consumption of surface water as drinking water are low and likely to be negligible. Conservative exposure models (i.e., erring on the side of over-estimating exposure) suggest potentially elevated health risks may exist for some human receptors regularly exposed to arsenic in water in the mine area at baseline.

Aquatic Health

The aquatic receptors selected for the baseline assessment were aquatic plants, invertebrates and fish living in surface water bodies as well as benthic invertebrates in the mine area.

Arsenic, aluminum, chromium, copper, iron, lead, mercury, nickel and zinc were considered of potential concern for aquatic receptors' health since their maximum measured baseline concentrations in surface water and/or sediment already exceeded water and/or sediment guidelines for protection of aquatic life.

Screening-level risk analyses of the baseline conditions related to surface water suggest iron and copper present potentially elevated risk levels to aquatic biota, including invertebrates and algae.

5.4.4 Impact Assessment

This section of the health assessment evaluates the potential adverse effects to human and aquatic health due to the Ambatovy mine in combination with the baseline conditions.

5.4.4.1 Issue Scoping

Consultation with stakeholders (Volume A, Section 6) and review of the previous EA for resource development in Madagascar identified the following health concerns:

- contamination of water resources used for human and animal consumption potentially affecting health of both children and adults;
- impacts of surface water quality and quantity on fishing and irrigation, both important livelihoods in the area; and
- impacts of water quality and quantity on abundance, health and survival of fish and other aquatic resources, especially from the Torotorofotsy Wetlands.

In addition to these concerns, professional judgment suggested other issues to consider would include potential changes in air and soil quality potentially affecting crops and the health of people.

Key questions established to address the potential adverse effects on human and ecological health due to the project and related developments 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 Mine Site Have on Human Health? |
| Key Question HH-2 | What Effect Will Chemical Releases From the Mine Site Have on Livelihood Resources? |
| Key Question EH-1 | What Effect Will Chemical Releases From the Mine Site Have on Aquatic Life Health? |

The following sections provide the methodology and assessment which address each of the above questions.

5.4.4.2 Key Question HH-1 What Effect Will Chemical Releases From the Mine Site Have on Human Health?

The following potential impact pathways between the mine project and human health were evaluated:

- between changes in water quality and human health;
- between changes in air quality and human health;
- between changes in soil quality and human health; and
- between changes in food quality and human health.

Water Quality

People in the study area depend on watercourses for drinking water (Volume K, Social Appendices). Some water quality parameters may change by more than 10% depending on the season, from the baseline conditions during mine operation, and then return to baseline conditions after mine closure (Water Quality Assessment, this volume). Some of those chemicals might be of concern for human health (Table 5.4-1).

Air Quality

During the operation phase, people may be exposed to chemicals released into the air from the mine project (Air Quality EA, Section 3.4, this volume).

Fish Quality

Some of the chemicals for which levels in surface water are expected to increase can bioaccumulate in fish tissue and fish are an important food resource in the

area. Fish may be a very important element in nutrition for certain local populations. At some areas (Ampitambe and Sakalava) people often eat fish daily between mid-April and mid-February (Volume K, Social Appendices).

Table 5.4-1 Water Quality Parameters Expected to Change During Mine Operations at Clarification Pond Outlets

| Substances | Antsahalava River Outlet | Sahaviara River Outlet | Sahamarirana River Outlet | Torotorofotsy River Outlet | Sakalava River Outlet | Ankaja River Outlet |
|------------|--------------------------|------------------------|---------------------------|----------------------------|-----------------------|---------------------|
| fluoride | X | | | | | |
| sodium | X | X | | | | |
| sulphate | X | X | X | X | X | X |
| arsenic | X | X | X | X | X | X |
| barium | X | X | X | X | X | X |
| chromium | X | X | X | X | X | X |
| molybdenum | X | X | X | X | X | X |
| selenium | X | X | X | X | X | X |
| thallium | X | X | X | X | X | X |
| zinc | X | X | | | | |

Note: "X" represents a predicted potential change during operations of more than 10% in relation to the baseline conditions, see Volume I, Appendix 9.2 for details.

Soil Quality

Chemicals released during mine operation can be deposited onto soil and people can accidentally ingest or be in contact with soil if it is transported off-site. People can also inhale dust particles generated from those potentially impacted soils.

Produce Quality

Rural livelihoods are largely based on subsistence agriculture, predominantly rice and manioc (Volume K, Appendix 3.1, Land Use). Potential changes to soil quality due to deposition of airborne contaminants could lead to increase of chemicals in vegetables through root or foliar uptake.

Properties of Cobalt

During consultation, a question was posed regarding the extraction of cobalt, the perceived radioactive properties of this mineral and its potential health risks (Volume A, Section 6). However, the primary form of radioactive cobalt is synthesized (i.e., does not occur naturally) for commercial and medical purposes, and does not pose a natural radioactive hazard. In other words, an individual is rarely exposed to radioactive cobalt unless undergoing radiation therapy (ATSDR 2004). There is no valid impact pathway between cobalt levels and

human health, because no change will be induced by the project, and therefore this topic was not assessed further.

Assessment Methods

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 methodological approach as well as receptor parameters and toxicity reference values are presented in the Human and Ecological Health Appendix (Volume K, Appendix 4.2).

Impact Description Criteria

The assessment criteria used for interpreting impacts to human health is presented in Table 5.4-2.

Table 5.4-2 Assessment Criteria for Evaluation of Human Health Effects

| Resource | Direction ^(a) | Magnitude ^(b) | Geographic Extent ^(c) | Duration ^(d) | Reversibility ^(e) | Frequency ^(f) |
|--------------|--|---|--|--|--|---|
| human health | positive (beneficial in nature), negative (adverse in nature), or neutral for the measurement endpoints | negligible: $HQ \leq 0.2$ and $ILCR \leq 1 \times 10^{-5}$ or no change from Baseline Case low and likely to be negligible: $0.2 > HQ \leq 10$ and between 1×10^{-5} a $ILCR \leq 1 \times 10^{-4}$ potentially elevated: $HQ > 10$ and $ILCR > 1 \times 10^{-4}$ | local: effect restricted to the LSA regional: effect extends beyond the LSA into the RSA beyond regional: effect extends beyond the RSA | short-term: construction medium-term: operation long-term: post-closure | reversible or irreversible | low: occurs once medium: occurs intermittently high: occurs continuously |

^(a) Direction: positive (beneficial to, or protective of health) or negative (adverse towards health).

^(b) Magnitude: degree of change to analysis endpoint: potential incremental lifetime cancer risk (ILCR) for carcinogenic chemicals and hazard quotient (HQ) for carcinogenic chemicals.

^(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.

LSA = local study area.

RSA = regional study area.

Results

Drinking Water Risk Results

Although cadmium and nickel were considered chemicals of potential concern in drinking water during baseline investigations (See Section 5.4.3 Baseline Summary) no incremental impact to human health from these metals is expected

during mine operation because their concentrations in surface water are predicted to be very similar to current levels.

Parameters that were predicted to be present at concentrations greater than the baseline case concentrations (Table 5.4-1) were compared with drinking water guidelines. In the absence of national (Madagascar) water quality guidelines for drinking water quality, international guidelines were used (WHO 2004). Maximum contaminant levels recommended by the USEPA (2002) for thallium (0.002 mg/L) was used for screening purposes since that parameter was not listed in the World Health Organization (WHO) document.

The only chemical retained for a risk assessment was thallium because the predicted concentration could be above the drinking water guideline during operations. However, the situation is unclear, since all baseline measures were below the detection limit of 0.009 mg/L and all predicted operational levels would also be below the detection limit, as is the only available guideline (USEPA 2002). Thus baseline levels may be above the guideline as well. However, exposure from drinking water during operations was calculated using worst-case levels at those pond outlets where values were >0.002 mg/L (guideline). The predicted daily dose was then divided by a benchmark dose (i.e., reference dose [RfD] which represents an acceptable daily dose free of health effects over a life time of exposure) to estimate the hazard quotient (HQ).

Using conservative assumptions and models, the results indicate low to negligible non-carcinogenic health risks to key receptors associated with exposure to thallium based on predicted concentrations in drinking water from all rivers (Volume I, Appendix 9.2). The maximum estimated risk (HQ = 3.9) was based on concentrations of thallium at the outlet of the Antsahalava River and is very similar to that calculated using baseline concentrations (HQ = 2.5). Predicted average concentrations further downstream from the outlet are equal or lower than the values at the outlets. Therefore potential health risks associated with ingestion of water from the six assessed rivers are considered to be low to negligible.

Fish Ingestion Risk Results

Fish tissue concentrations of arsenic, barium, chromium, molybdenum, selenium, thallium and zinc were estimated using their annual measured (baseline) and predicted (operation) levels in water and fish bioconcentration factors. The administered doses via fish ingestion were then calculated and divided by benchmark doses representing acceptable risk (RfD) to estimate the hazard quotient. Arsenic was not assessed further since predicted fish concentrations met guidelines for fish consumption (3.5 mg/kg, Health Canada, Canadian Food Inspection Agency 2005).

Fluoride and sodium were not considered of concern because fish control their uptake through normal gill functions. Therefore levels of fluoride and sodium in fish tissue are not expected to significantly increase even if concentrations in water rise.

Sulphate was also not assessed with respect to fish tissue quality and its consumption as sulphate is unlikely to accumulate due to gill functions and its rapid transformation in the aquatic and physiological environments.

The results indicate low to negligible non-carcinogenic health risks to critical receptors associated with exposure to barium, molybdenum, selenium and zinc due to increased fish tissue concentrations during mine operation (Volume I, Appendix 9.2). The estimated risks for those metals were based on average predicted levels in the six assessed rivers at the outlet of the mine. Concentrations downstream from the outlet are expected to be equal or lower than at the outlet.

Initial analysis of thallium suggested human health risk to children was "potentially high" via the fish consumption pathway. Considerable uncertainty existed though for the potentially elevated risk from thallium in fish. In part this is a consequence of an elevated detection limit used during accelerated leach tests to predict the environmental fate of thallium. In fact, thallium was actually recorded as "non-detectable" during such tests. Assuming thallium was present at half the detection limit (normal procedure for non-detected concentrations) the subsequent risk calculations incorporated a high theoretical bio-concentration factor for fish and suggested an apparent health risk for children who might consume these fish (Volume K, Appendix 4.2). This computation and result is in fact similar to the baseline condition which has similar uncertainty.

As a result of this uncertainty, additional accelerated leach tests of mine ferrallite material were conducted with analytical detection 50-fold lower than previously employed (0.0008 mg/L). Even with this improved detection limit, thallium remained non-detectable in accelerated leach tests, indicating the absence or very low level of thallium. This 50-fold reduction in detection, combined with mine

water dilution dynamics mean that the risk estimates are in fact not "potentially high", but rather negligible (i.e., HQ < 10). This revised assessment is further supported by the analyses done on tailings effluent, where again thallium was not detected with a detection limit at 0.0002 mg / L (Volume K, Appendix 4.2).

Conservative assumptions and exposure models suggest an incremental health risk (in addition to the risk at baseline) may be observed due to changes in chromium concentrations in surface water and consequent potential bioaccumulation in fish tissue. The results suggest potentially high risks from fish consumption in the Sakalava, Ankaja, and Torotorofotsy basins downstream from the outlet.

Air Risk Results

Predicted values based on air emission and dispersion modelling for maximum 1-hour, 24-hour and annual concentrations of chemicals in air were compared with available acute and chronic exposure limits (1-hour, 24-hour and annual air quality guidelines). Table 5.4-3 presents the highest air concentrations expected to be found in the study area, (i.e., in the location of the Sakalava community). Concentrations of all substances were less than available exposure limits (i.e., no airborne contaminant of concern). Therefore no health effects are expected to occur in any of the accessed communities due to short or medium-term emissions from the mine site.

Soil Ingestion Risk Results

Incremental concentrations of metals and polycyclic aromatic hydrocarbons (PAHs) in surface soil were estimated using air deposition rates from chemicals expected to be emitted during mining operations. Deposition rates estimated for Ambohimamarivo and Sakalava community areas were used for calculations since they correspond to the highest deposition rates among all twenty communities evaluated. The total dose was estimated for each chemical from three different pathways: accidental soil ingestion, dermal contact and dust inhalation.

Results suggest incremental health risks would be negligible (Volume I, Appendix 9.2). Since the soil concentrations at all other communities are expected to be equal or lower than the levels predicted for Ambohimamarivo and Sakalava Ambony, the incremental risk for all other communities were also considered negligible.

Table 5.4-3 Comparison Between Predicted Air Quality During Mine Operation and Air Quality Guidelines

| Parameter | Air Quality Guidelines [µg/m³] | | | Predictions - Maximum Values ⁽ⁱ⁾ [µg/m³] | | |
|-------------------|-----------------------------------|------------------------|----------------------|--|-----------|--------|
| | 1-hr max | 24-hr max | Annual | 1-hr max | 24-hr max | Annual |
| SO ₂ | 500 ^(a,b) | 125 ^(a) | 50 ^(a) | 29.2 | 5.9 | 2.6 |
| NO ₂ | 200 ^(a,b) | 40 ^(a) | 120 ^(a) | 110.2 | 26.5 | 10.2 |
| PM _{2.5} | - | 65 ^(d) | 15 ^(d) | not estimated | 1.1 | 0.2 |
| PM ₁₀ | - | 150 ^(d) | 50 ^(d) | not estimated | 1.8 | 0.3 |
| TSP | - | 120-400 ^(c) | 60-70 ^(c) | not estimated | 1.8 | 0.4 |
| aluminum | 300 ^(e,h) | 120 ^(f,h) | 24 ^(g,h) | 5.8353 | 1.0788 | 0.3570 |
| arsenic | 0.75 ^(e) | 0.3 ^(f) | 0.06 ^(g) | 0.0015 | 0.0001 | 0.0000 |
| barium | 25 ^(e) | 10 ^(f) | 2 ^(g) | 0.0029 | 0.0002 | 0.0001 |
| beryllium | 0.025 ^(e) | 0.01 ^(f) | 0.002 ^(g) | 0.0000 | 0.0000 | 0.0000 |
| cadmium | 5 ^(e) | 2 ^(f) | 0.4 ^(g) | 0.0049 | 0.0012 | 0.0004 |
| chromium | 3.75 ^(e) | 1.5 ^(f) | 0.3 ^(g) | 0.0020 | 0.0003 | 0.0001 |
| cobalt | 0.25 ^(e) | 0.1 ^(f) | 0.02 ^(g) | 0.1103 | 0.0197 | 0.0064 |
| copper | 125 ^(e) | 50 ^(f) | 10 ^(g) | 0.0028 | 0.0004 | 0.0001 |
| lead | 1.75 ^(e) | 0.7 ^(f,g) | 0.14 ^(g) | 0.0025 | 0.0003 | 0.0001 |
| manganese | 6.25 ^(e) | 2.5 ^(f) | 0.5 ^(g) | 0.6097 | 0.1124 | 0.0371 |
| mercury | 5 ^(e) | 2 ^(f) | 0.4 ^(g) | 0.0001 | 0.0000 | 0.0000 |
| molybdenum | 300 ^(e) | 120 ^(f) | 24 ^(g) | 0.0009 | 0.0001 | 0.0000 |
| nickel | 5 ^(e) | 2 ^(f) | 0.4 ^(g) | 1.1642 | 0.2053 | 0.0659 |
| selenium | 25 ^(e) | 10 ^(f) | 2 ^(g) | 0.0008 | 0.0001 | 0.0000 |
| vanadium | 5 ^(e) | 2 ^(f) | 0.4 ^(g) | 0.0364 | 0.0030 | 0.0008 |
| zinc | 300 ^(e) | 120 ^(f) | 24 ^(g) | 0.0385 | 0.0041 | 0.0008 |

^(a) WHO (2000).

^(b) Averaging time: 10 minutes.

^(c) Canadian Council of Ministers of the Environment (CCME) (2002).

^(d) USEPA (<http://www.epa.gov/air/criteria.html> accessed in October 2005).

^(e) OME (2001). Calculated from 24 hours guidelines using Averaging Time Conversion Factors (OME 2004).

^(f) OME (2001).

^(g) 0.7 - 30 Days +; otherwise 2.

^(h) Guideline for aluminum oxide.

⁽ⁱ⁾ Values predicted for the Ambony Sakalava community located 8.8 Km north of the mine site.

TSP = Total suspended solids.

Produce Ingestion Risk Results

Incremental levels of chemicals in below-ground vegetables (i.e., roots such as manioc) were estimated based on soil concentration and soil to root bioconcentration factors. Levels of chemicals in above-ground vegetables (e.g., rice) were calculated using both air deposition rates and soil to root uptake of chemicals.

The total dose for each chemical was then estimated from ingestion of both below and above-ground vegetables. Non-carcinogenic risks were estimated for a child and carcinogenic risks for a composite receptor. Results are presented in Volume K, Appendix 4.2, Section 1.4. Incremental risk due to vegetables ingestion was considered negligible for both receptors.

5.4.4.3 Key Question HH-2 What Effect Will Chemical Releases From the Mine Site Have on Livelihood Resources?

The assessment of the key question HH-2 is focused on effects on fisheries as well as crops production and zebu health. According to the socioeconomic baseline assessment (Volume K, Section 1.1) the rural economy in the mine area is largely based on the cultivation of rice and manioc. Livestock and animal husbandry and forest and wild products gathering represent only 4% and 1% of household income in the area respectively. In the area of the mine, zebu cattle are primarily used for work on rice paddies and transport and has a symbolic value and cultural significance.

Water Quality

Some water quality parameters are predicted to change more than 10% in surface waters affected by mine operations (Table 5.4-1). Changes in water quality could therefore potentially affect livelihood resources.

Assessment Methods

Produce and Livestock

Annual baseline and predicted levels of calcium fluoride, sodium, sulphate, arsenic, chromium, molybdenum, selenium and zinc were compared with guideline values for irrigation water and livestock watering (South African Water Quality Guidelines, DWAF 1996 a and b). Guidelines were not available for thallium and barium. Parameters for which concentrations were above guidelines were considered of potential concern for agricultural use.

Fish

Potential impacts on fisheries 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 the Key Question EH-1 (see Section 5.4.4.4).

Impact Description Criteria

The assessment criteria used for evaluation of potential effects on livelihood resources is presented in the table below.

Table 5.4-4 Assessment Criteria for Evaluation of Effects on Livelihood Resources

| Resource | Direction ^(a) | Magnitude ^(b) | Geographic Extent ^(c) | Duration ^(d) | Reversibility ^(e) | Frequency ^(f) |
|----------------------|---|--|--|--|---|---|
| livelihood resources | positive (beneficial in nature), negative (adverse in nature) or neutral for the measurement endpoints | negligible: below applicable guidelines or no change from Baseline Case low and likely to be negligible: 10-100% higher than guidelines potentially elevated: > 100% higher than guidelines | local: effect restricted to the LSA regional: effect extends beyond the LSA into the RSA beyond regional: effect extends beyond the RSA | short-term: construction medium-term: operation long-term: post-closure | reversible or irreversible | low: occurs once medium: occurs intermittently high: occurs continuously |

(a) Direction: positive (beneficial to, or protective of health), or negative (adverse towards health).

(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.

Results

Produce and Livestock

All parameters met the guidelines for both irrigation and livestock drinking water (for those which guidelines were available) at the outlet of each assessed river (Table 5.4-5). Therefore the operation of the mine facility is unlikely to pose incremental risk to community livelihoods due to irrigation and livestock watering.

Table 5.4-5 Baseline and Predicted (Operation Phase) Annual Concentration in Surface Water in the Mine Area and Guidelines for Water Quality for Agricultural Use

| Basins | Units | South Africa Water Quality Guidelines Livestock Watering ^(a) | South Africa Water Quality Guidelines Irrigation ^(a) | Average Annual Concentration (mg/L) - Outlet | | | | |
|-----------------------------|-------|---|--|--|---------|---------|---------|---------|
| | | | | Baseline | Year 4 | Year 10 | Year 15 | Year 20 |
| Antsahalava River | | | | | | | | |
| fluoride (F) | mg/L | 0-2 | ng | 0.05 | 0.05 | 0.06 | 0.05 | 0.06 |
| sodium (Na) | mg/L | 0-2000 | 0-70 | 2.3 | 2.6 | 2.8 | 2.6 | 2.7 |
| sulphate (SO ₄) | mg/L | 0-1000 | ng | 1.4 | 2.4 | 2.6 | 2.4 | 2.5 |
| arsenic (As) | mg/L | 0-1 | 0-0.1 | 0.0019 | 0.0026 | 0.0029 | 0.0026 | 0.0027 |
| barium (Ba) | mg/L | ng | ng | 0.017 | 0.078 | 0.106 | 0.081 | 0.090 |
| chromium (Cr) | mg/L | 0-1 (Cr IV) | 0-0.10 (Cr IV) | 0.007 | 0.023 | 0.024 | 0.023 | 0.023 |
| molybdenum (Mo) | mg/L | 0-0.01 | 0-0.01 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 |
| selenium (Se) | mg/L | 0-50 | 0-2.0 | 0.002 | 0.002 | 0.003 | 0.003 | 0.003 |
| thallium (Tl) | mg/L | ng | ng | < 0.006 | < 0.008 | < 0.008 | < 0.008 | < 0.008 |
| zinc (Zn) | mg/L | 0-20 | 0-1.0 | 0.006 | 0.007 | 0.008 | 0.008 | 0.008 |
| Sahaviara River | | | | | | | | |
| sodium (Na) | mg/L | 0-2000 | 0-70 | 2.3 | 2.2 | 2.2 | 2.7 | 2.4 |
| sulphate (SO ₄) | mg/L | 0-1000 | ng | 1.4 | 2.0 | 2.0 | 2.5 | 2.2 |
| arsenic (As) | mg/L | 0-1 | 0-0.1 | 0.0019 | 0.0023 | 0.0023 | 0.0028 | 0.0025 |
| barium (Ba) | mg/L | ng | ng | 0.017 | 0.071 | 0.071 | 0.120 | 0.093 |
| chromium (Cr) | mg/L | 0-1 (Cr IV) | 0-0.10 (Cr IV) | 0.007 | 0.018 | 0.018 | 0.020 | 0.019 |
| molybdenum (Mo) | mg/L | 0-0.01 | 0-0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 |
| selenium (Se) | mg/L | 0-50 | 0-2.0 | 0.002 | 0.002 | 0.002 | 0.003 | 0.002 |
| thallium (Tl) | mg/L | ng | ng | < 0.006 | < 0.008 | < 0.008 | < 0.008 | < 0.008 |
| zinc (Zn) | mg/L | 0-20 | 0-1.0 | 0.006 | 0.007 | 0.007 | 0.008 | 0.007 |
| Sahamarirana River | | | | | | | | |
| sulphate (SO ₄) | mg/L | 0-1000 | ng | 1.4 | 2.2 | 2.2 | 1.6 | 1.5 |
| arsenic (As) | mg/L | 0-1 | 0-0.1 | 0.0019 | 0.0022 | 0.0022 | 0.0019 | 0.0019 |
| barium (Ba) | mg/L | ng | ng | 0.017 | 0.062 | 0.064 | 0.036 | 0.039 |
| chromium (Cr) | mg/L | 0-1 (Cr IV) | 0-0.10 (Cr IV) | 0.007 | 0.025 | 0.025 | 0.013 | 0.010 |
| molybdenum (Mo) | mg/L | 0-0.01 | 0-0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| selenium (Se) | mg/L | 0-50 | 0-2.0 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| thallium (Tl) | mg/L | ng | ng | < 0.006 | < 0.007 | < 0.007 | < 0.007 | < 0.007 |
| Torotorofotsy River | | | | | | | | |
| sulphate (SO ₄) | mg/L | 0-1000 | ng | 1.4 | 1.4 | 1.7 | 1.4 | 1.9 |
| arsenic (As) | mg/L | 0-1 | 0-0.1 | 0.0019 | 0.0019 | 0.0023 | 0.0020 | 0.0022 |
| barium (Ba) | mg/L | ng | ng | 0.017 | 0.017 | 0.039 | 0.023 | 0.033 |
| chromium (Cr) | mg/L | 0-1 (Cr IV) | 0-0.10 (Cr IV) | 0.007 | 0.007 | 0.048 | 0.019 | 0.044 |
| molybdenum (Mo) | mg/L | 0-0.01 | 0-0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| selenium (Se) | mg/L | 0-50 | 0-2.0 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| thallium (Tl) | mg/L | ng | ng | < 0.006 | < 0.007 | < 0.007 | < 0.007 | < 0.007 |

Table 5.4-5 Baseline and Predicted (Operation Phase) Annual Concentration in Surface Water in the Mine Area and Guidelines for Water Quality for Agricultural Use (continued)

| Basins | Units | South Africa Water Quality Guidelines Livestock Watering ^(a) | South Africa Water Quality Guidelines Irrigation ^(a) | Average Annual Concentration (mg/L) - Outlet | | | | |
|-----------------------------|-------|---|---|--|--------|---------|---------|---------|
| | | | | Baseline | Year 4 | Year 10 | Year 15 | Year 20 |
| Sakalava River | | | | | | | | |
| sulphate (SO ₄) | mg/L | 0-1000 | ng | 1.4 | 1.4 | 1.5 | 1.9 | 1.4 |
| arsenic (As) | mg/L | 0-1 | 0-0.1 | 0.0019 | 0.0019 | 0.0019 | 0.0022 | 0.0019 |
| barium (Ba) | mg/L | ng | ng | 0.017 | 0.017 | 0.020 | 0.035 | 0.019 |
| chromium (Cr) | mg/L | 0-1 (Cr IV) | 0-0.10 (Cr IV) | 0.007 | 0.007 | 0.015 | 0.048 | 0.012 |
| molybdenum (Mo) | mg/L | 0-0.01 | 0-0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| selenium (Se) | mg/L | 0-50 | 0-2.0 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| thallium (Tl) | mg/L | ng | ng | <0.006 | <0.007 | <0.007 | <0.007 | <0.007 |
| Ankaja River | | | | | | | | |
| sulphate (SO ₄) | mg/L | 0-1000 | ng | 1.4 | 1.7 | 1.5 | 1.4 | 1.8 |
| arsenic (As) | mg/L | 0-1 | 0-0.1 | 0.0019 | 0.0021 | 0.0021 | 0.0018 | 0.0021 |
| barium (Ba) | mg/L | ng | ng | 0.017 | 0.035 | 0.034 | 0.020 | 0.033 |
| chromium (Cr) | mg/L | 0-1 (Cr IV) | 0-0.10 (Cr IV) | 0.007 | 0.048 | 0.041 | 0.018 | 0.047 |
| molybdenum (Mo) | mg/L | 0-0.01 | 0-0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| selenium (Se) | mg/L | 0-50 | 0-2.0 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| thallium (Tl) | mg/L | ng | ng | <0.006 | <0.007 | <0.007 | <0.007 | <0.007 |

Notes:

All predicted values met South African guidelines for livestock and irrigation.

Parameters with concentrations predicted to be not 10% greater in the application case (for all operation and post-closure years) than baseline case are not listed in this table (all predicted values are presented in the Water Quality Assessment, Volume B, Section 3.9).

ng = No guideline.

^(a) Target water quality range (Department of Water Affairs and Forestry, 1996).

Fish

Effects on fish and fish food (algae and invertebrates) due to chemical emissions from the mine site were considered 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 EA of Fish and Aquatic Resources section in this volume (Section 4.3).

5.4.4.4 Key Question EH-1 What Effect Will Chemical Releases From the Mine Site Have on Aquatic Health?

Both water quality and sediment quality are considered as potential impact pathways.

Water Quality

Aquatic health can be directly affected by changes in physical or chemical water characteristics. Levels of some chemicals were conservatively predicted to increase more than 10% in relation to background conditions during mine operation. Aquatic health could potentially be affected by those changes in water quality.

Sediment Quality

Invertebrates which inhabit sediments and collectively form the benthic community could potentially be affected by changes in sediment conditions. Non-benthic aquatic organisms can also be indirectly affected (e.g., decreasing of food resources).

Assessment Methods

Water and Sediment Quality

The evaluations were conducted according to established risk assessment methods endorsed by the USEPA (1998) framework. Refer to Human and Ecological Health Appendix (Volume K, Section 4.2) for description of detailed methodological approach. Predicted environmental concentrations for contaminants of concern were divided by toxicity reference values for algae, invertebrates and fish (Suter 1996) to calculate Hazard Quotients (HQ).

Impact Description Criteria

The assessment criteria used for ecological health is presented in the following table.

Table 5.4-6 Assessment Criteria for Evaluation of Effects on Aquatic Life

| Resource | Direction ^(a) | Magnitude ^(b) | Geographic Extent ^(c) | Duration ^(d) | Reversibility ^(e) | Frequency ^(f) |
|---------------------|---|--|--|--|--|---|
| aquatic life health | positive (beneficial in nature), negative (adverse in nature) or neutral for the measurement endpoints | negligible HQ≤1 or no change from Baseline Case Low and likely to be negligible: HQ>1 and ≤10 Potentially elevated: HQ>10 | local: effect restricted to the LSA regional: effect extends beyond the LSA into the RSA beyond regional: effect extends beyond the RSA | short-term: construction medium-term: operation long-term: post-closure | reversible or irreversible | low: occurs once medium: occurs intermittently high: occurs continuously |

^(a) Direction: positive (beneficial to, or protective of health) or negative (adverse towards health).

^(b) Magnitude: degree of change to analysis endpoint: potential incremental hazard quotient (HQ).

^(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.

Results

Water Quality

Although aluminum, iron, copper, lead and manganese were considered chemicals of potential concern in the baseline risk assessment (Section 5.4.3 Baseline Summary) they were not assessed further because predicted concentrations are similar to the baseline conditions and hence no incremental risk for aquatic life is expected for these chemicals.

Water quality parameters which were conservatively predicted to change due to the operation of the mine (Section 3.9, this volume) were screened against South African Guidelines for Aquatic Ecosystems (DWAF 1996). Alternative references were used for sulphate (100 mg/L) and barium (1 mg/L) which are not listed in the South African document (Recommended Guideline for Freshwater Aquatic Life by Province of British Columbia, 2001). These screening criteria suggested fluoride, sulphate, arsenic, barium and zinc were not chemicals of concern and therefore did not warrant further consideration.

Sodium, chromium, molybdenum, thallium and selenium, however, were retained for further analysis because no screening guideline values were available (for sodium, molybdenum and thallium) and because concentrations of selenium exceeded guidelines. The calculated hazard quotients (HQs) for each type of organism are presented in the Table 5.4-7. The HQs for all chemicals were considered negligible. Therefore incremental risk to aquatic life due to mine operations is considered unlikely.

Table 5.4-7 Hazard Quotients (HQs) for the Aquatic Fauna in the Mine Area - Outlet

| | Annual Average | | HQ Aquatic Plant | | HQ Invertebrates | | HQ Fish | | Magnitude of the Risk |
|----------------------------|--|--|------------------|-------------------|------------------|-------------------|----------|-------------------|-----------------------|
| | Measured Values - Baseline ^(a) (mg/L) | Average Operation - Predicted Values ^(b) (mg/L) | Baseline | Average Operation | Baseline | Average Operation | Baseline | Average Operation | Average Operation |
| Antsahalava River Outlet | | | | | | | | | |
| sodium (Na) | 2.3 | 2.7 | nd | nd | 0.00 | 0.00 | nd | nd | negligible |
| chromium (Cr) | 0.007 | 0.023 | 0.02 | 0.06 | 0.17 | 0.53 | 0.01 | 0.03 | |
| molybdenum (Mo) | 0.00 | 0.01 | nd | nd | 0.00 | 0.01 | nd | nd | |
| selenium (Se) | 0.002 | 0.003 | 0.02 | 0.03 | 0.02 | 0.03 | 0.02 | 0.03 | |
| thallium (Tl) | 0.0045 ^(d) | 0.01 | 0.05 | 0.07 | 0.03 | 0.05 | 0.08 | 0.12 | |
| zinc (Zn) | 0.006 | 0.008 | 0.21 | 0.26 | 0.13 | 0.17 | 0.17 | 0.21 | |
| Sahaviara River Outlet | | | | | | | | | |
| sodium (Na) | 2.3 | 2.4 | nd | nd | 0.00 | 0.00 | nd | nd | negligible |
| chromium (Cr) | 0.007 | 0.019 | 0.02 | 0.05 | 0.17 | 0.42 | 0.01 | 0.02 | |
| molybdenum (Mo) | 0.00 | 0.01 | nd | nd | 0.00 | 0.01 | nd | nd | |
| selenium (Se) | 0.002 | 0.002 | 0.02 | 0.02 | 0.02 | 0.03 | 0.02 | 0.03 | |
| thallium (Tl) | 0.0045 ^(d) | 0.01 | 0.05 | 0.06 | 0.35 | 0.47 | 0.08 | 0.11 | |
| zinc (Zn) | 0.006 | 0.007 | 0.21 | 0.23 | 0.13 | 0.15 | 0.17 | 0.19 | |
| Sahamarirana River Outlet | | | | | | | | | |
| chromium (Cr) | 0.007 | 0.018 | 0.02 | 0.05 | 0.17 | 0.41 | 0.01 | 0.02 | negligible |
| molybdenum (Mo) | 0.00 | 0.00 | nd | nd | 0.00 | 0.00 | nd | nd | |
| selenium (Se) | 0.002 | 0.002 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | |
| thallium (Tl) | 0.0045 ^(d) | 0.01 | 0.05 | 0.06 | 0.03 | 0.04 | 0.08 | 0.10 | |
| Torotorofotsy River Outlet | | | | | | | | | |
| chromium (Cr) | 0.007 | 0.030 | 0.02 | 0.07 | 0.17 | 0.68 | 0.01 | 0.03 | negligible |
| molybdenum (Mo) | 0.00 | 0.00 | nd | nd | 0.00 | 0.00 | nd | nd | |
| thallium (Tl) | 0.0045 ^(d) | 0.01 | 0.05 | 0.06 | 0.03 | 0.04 | 0.08 | 0.10 | |
| Sakalava River Outlet | | | | | | | | | |
| chromium (Cr) | 0.007 | 0.021 | 0.02 | 0.05 | 0.17 | 0.47 | 0.01 | 0.02 | negligible |
| molybdenum (Mo) | 0.00 | 0.00 | nd | nd | 0.00 | 0.00 | nd | nd | |
| thallium (Tl) | 0.0045 ^(d) | 0.01 | 0.05 | 0.05 | 0.03 | 0.04 | 0.08 | 0.09 | |
| Ankaja River Outlet | | | | | | | | | |
| chromium (Cr) | 0.007 | 0.038 | 0.02 | 0.10 | 0.17 | 0.87 | 0.01 | 0.04 | negligible |
| molybdenum (Mo) | 0.00 | 0.002 | nd | nd | 0.00 | 0.00 | nd | nd | |
| thallium (Tl) | 0.0045 ^(d) | 0.006 | 0.05 | 0.06 | 0.03 | 0.05 | 0.08 | 0.10 | |

^(a) Measured average concentration (dry and wet seasons) (See Water Quality Session in this volume).

^(b) Predicted average annual concentration (operation average years 4, 10, 15 and 20, dry and wet seasons).

^(c) Only chemicals of potential concern for aquatic life are listed (For further details refer to Water Quality Assessment, this volume).

^(d) Baseline values <0.009 mg/L (detection limit): 0.5x detection limit used in calculations.

Toxicological Benchmarks based on the Lowest Chronic Values (Suter 1996) (mg/L) (See Human and Ecological Risk Assessment Methodology, Volume K, Appendix 4.2).

nd = Not determined.

HQ>10 in bold.

Sediment Quality

Copper and nickel were considered chemicals of potential concern in the baseline risk assessment (Section 5.4.3) but they were not further assessed because concentrations during operation and post-close of the facility are predicted to be similar to the baseline conditions (i.e., no incremental effect from mine operation).

Levels of arsenic, selenium and thallium in sediment are predicted to change (>10%) during mine operation (Water Quality Assessment, this volume). However, since predicted concentrations of arsenic and selenium met guideline values (Canadian Sediment Quality Guidelines 2002 and British Columbia 2001 respectively) no further evaluation was warranted for these two chemicals. In the case of thallium, no sediment quality guidelines and / or toxicity-based reference values were identified

5.4.4.5 Mitigation

Mitigations that are applicable to human and aquatic health were discussed previously in the Water and Air Quality Assessment, this volume.

5.4.4.6 Residual Impacts

The residual impact classifications are provided in Table 5.4-8. They have been assessed as local (limited to the watersheds directly affected by the mine site (restricted to the local study area), long-term (lasting after the site closure), reversible and of high frequency (occurring continuously).

The magnitude of the impact was considered as negligible to livelihood resources, low to negligible to aquatic life and generally low to negligible for human health, with the exception of potentially high for chrome. The actual situation with chrome needs to be monitored. Owing to the many conservative assumptions in the models, realized chromium values may be less than predicted.

Table 5.4-8 Residual Impact Classification for the Mine Site 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 Mine Site Have on Human Health? | | | | | | |
| negative | low to negligible for all parameters, except potentially high for chrome | local | long-term (operation and post-closure) | reversible | high | low to negligible for all parameters except potentially high for chrome |
| Key Question HH-2 What Effect Will Chemical Releases From the Mine Site Have on Livelihood Resources? | | | | | | |
| neutral | n/a | n/a | n/a | n/a | n/a | n/a |
| Key Question EH-1 What Effect Will Chemical Releases From the Mine Site Have on Aquatic Life Health? | | | | | | |
| potentially negative | low to negligible | local | long-term (operation and post-closure) | reversible | high | low to negligible |

Note: n/a is not applicable (Neutral impacts not quantified).

5.4.4.7 Monitoring

In addition to monitoring described in the Water and Air Quality Sections, fish tissue sampling is also recommended especially as regards chrome (for further details refer to Environmental Management Plans, Volume B, Section 7).

5.4.5 Conclusions

The human and ecological health assessment evaluated the potential for adverse effects to health associated with chemical emissions from the mine site in combination with baseline conditions.

Potential impacts on human health due to possible changes in water, soil, air and produce quality were considered negligible. Levels of chromium in fish tissue may rise to levels of potential concern to human consumption. However, these predictions were based on conservative predictive modeling with respect to chromium release to the surface water. Also, site-specific bioconcentration factors, i.e., factors estimated using fish species found in the mine study area, may differ from the ones found in the literature and this apparent health risk may prove negligible. Water and fish tissue monitoring are thus proposed to confirm exposure and allow re-estimation of risk analyses presented here.

Impacts on livelihood resources, including agriculture, livestock and fisheries due to changes in water quality during mine operation are considered negligible.

For fisheries, this conclusion results from dilution effects downstream from the mine and the fact that most parameters represent low to negligible risk even at the pond outlets. However, as noted above monitoring for chrome especially is planned for fish tissue, both prior to and during construction/operations. The health and survival of fish and other aquatic resources, including organisms living the Torotorofotsy Wetlands, are also unlikely to be affected by the mine (refer to Section 4, Biological Assessment, for further discussion of impacts of water quality on wildlife health as well as possible effects of physical changes such as sedimentation and water quantity depletion on fish and aquatic resources).

The assessment was based on many conservative assumptions (see “Layers of safety” in Volume K, Appendix 4.2. Human and Ecological Health Methodology). The prediction of confidence that risk has not been underestimated can be rated as moderate to high.

5.5 TRAFFIC

5.5.1 Introduction

This section presents the Environmental Assessment for the effects of the mine on traffic. As per the Ambatovy Project (the project) terms of reference, the changes in traffic levels are predicted and compared to baseline traffic levels. The effects of increased traffic is assessed qualitatively in relation to potential impacts on nearby residences, livestock and human safety.

5.5.2 Study Area

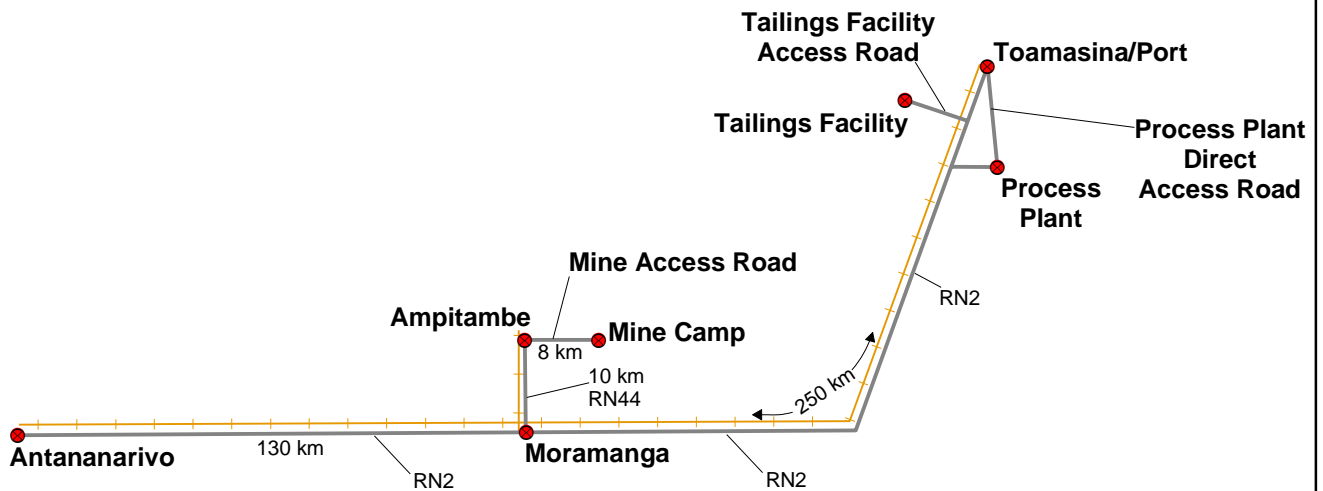
The key public access routes to be used for mine access traffic are Route Nationale (RN) 2, RN44 and the railway line from Toamasina to Moramanga. Effects on traffic along these routes are assessed. The mine access road between Ampitambe and the mine camp is also subject to some public use, and is discussed.

5.5.3 Baseline Summary

The key public access routes for the mine are RN2 from Toamasina and RN2 from Antananarivo to Moramanga, and RN44 from Moramanga to the mine access road. Both RN2 and RN44 are two-lane, paved roads in good condition. The access road from Ampitambe to the mine is a dirt road in moderate condition, which will be upgraded to a wider gravel road for the project.

Goods coming into or out of Madagascar largely move between Antananarivo and Toamasina, along the country's main highway, RN2. RN44 links to RN2 at Moramanga and is used heavily by agricultural truck traffic, as it services one of the country's main rice growing regions. Moramanga is about three hours' travel from Antananarivo (130 km along RN2) and five hours' travel from Toamasina (250 km along RN2). The mine access road is ten minutes (10 km) from Moramanga along RN44 (Figure 5.5-1).

Baseline traffic volumes over 24-hour periods for the key public access routes to be used by mine traffic are provided in Table 5.5-1.



LEGEND

- ROAD
- +— RAILWAY

REFERENCE

Not to Scale. Distances are approximate.

PROJECT

AMBATOVY PROJECT

TITLE

**SCHEMATIC DIAGRAM OF
MAJOR ACCESS ROUTES**



| | | | |
|---------|---------------------|--------------|--------|
| PROJECT | No.03-1322-172.8400 | NOT TO SCALE | REV. 0 |
| DESIGN | GJ 25 May, 2005 | | |
| GIS | LL 25 May, 2005 | | |
| CHECK | GJ 01 Feb. 2006 | | |
| REVIEW | DM 01 Feb. 2006 | | |

FIGURE: 5.5-1

Table 5.5-1 Baseline Traffic Level Summary

| Type of Vehicle | 24-hour traffic volume between Moramanga and Antananarivo (at edge of Moramanga) | | 24-hour traffic volume between Moramanga and Toamasina (at edge of Moramanga) | | 24-hour traffic volume between Moramanga and Ampitambe / mine access road | |
|---------------------------------|--|--------------|---|--------------|---|--------------|
| | Weekday | Weekend | Weekday | Weekend | Weekday | Weekend |
| private cars | 504 | 609 | 243 | 311 | 326 | 351 |
| transports for people | 449 | 354 | 212 | 253 | 204 | 212 |
| transports for goods | 555 | 647 | 346 | 447 | 319 | 243 |
| two-wheeled vehicles, motorized | 1,408 | 1,436 | 353 | 493 | 3,574 | 3,628 |
| unmotorized vehicles | 60 | 36 | 58 | 50 | 616 | 694 |
| total | 2,976 | 3,082 | 1,212 | 1,554 | 5,039 | 5,128 |

Accident rates under baseline conditions are expected to occur at approximately 3.12 per million vehicle kilometres on RN2 and RN44 (Volume K, Appendix 5.1).

5.5.4 Issue Scoping

Key issues relating to traffic raised during public consultations (Volume A, Section 6) include:

- Safety: the traffic on RN2, even under baseline conditions, is unsafe due to high speeds (comment from Moramanga).
- Noise and vibration: the existing traffic produces noise and vibration which currently affect houses along the road (comment from Moramanga).
- Traffic congestion in towns: large vehicles should bypass the town of Moramanga (comment from Moramanga).
- Accidents: with increased traffic volumes during the project how will an increase in accident rates be prevented (comment from the technical evaluation committee [CTE]).

It is recognized that the project may have several impacts relating to traffic, including:

- Increased disturbance due to dust, noise, vibrations and emissions to populations along the roadside, with a stronger impact along unpaved roads.
- Increased traffic flows and any increases in speed associated with improvements to roads made in relation to the project imply an increase in accidents, to both people and to their animals.
- Traffic accidents involving transport of industrial goods risk contamination of land and water resources from spills.
- Any road construction or improvement will cause temporary delays to non-project traffic.
- Increased traffic flows can imply increased congestion, specifically in the town of Moramanga, which already sees a significant amount of congestion as a result of the combination of transport traffic on urban streets that also have many pedestrians, bicycle riders, pousse-poussettes (rickshaws), and animals.
- While unlikely to occur along RN2, significantly increased traffic on RN44 may contribute to project-induced migration of population to the Moramanga area, specifically to the road sides.

There is no Key Question addressed in this section. While changes in traffic are described, the implications and impacts of changes in traffic are assessed in the socioeconomic section (Volume B, Section 5.1).

5.5.5 Changes in Traffic

5.5.5.1 Assessment Methods

The effects of traffic are assessed quantitatively for traffic volume and traffic accident rates, based on the extrapolation of existing baseline information. The approximate number of vehicles required for project operation is known and is used to calculate proportional effects in comparison to baseline conditions.

The effects of traffic on health, safety, vibration, noise and congestion in towns are assessed qualitatively.

5.5.5.2 Results

Traffic impacts will occur throughout the construction and operations phases of the project. Construction phase effects are often more extreme, as there is movement of equipment and construction materials to the site, construction workforces are generally larger than operational workforces, and construction itself – either to improve roads or to improve associated facilities along roads – can impede traffic flow.

Traffic Volumes

Changes in traffic volumes due to the project are based on estimates of the number of personal vehicles, supply trucks and buses (transporting workers) that will be required on a daily basis for the project to operate. The number of vehicles required is summarized for construction and operation phases of the project and for each main road segment in Table 5.5-2. These numbers represent a relatively small fraction of existing baseline traffic provided in Table 5.5-1.

Table 5.5-2 Vehicle Numbers per Day^(a)

| Project Phase | Vehicle Types | RN2, Moramanga-Toamasina | RN2, Moramanga-Antananarivo | RN44, Ampitambe-Moramanga |
|---|---------------|--------------------------|-----------------------------|-------------------------------|
| construction (3 years) (number of round trips per day) | cars | 0 | 0 | 10 |
| | trucks | 16 | 2 | 18 |
| | buses | 0 | 0 | 7 |
| | total | 16 | 2 | 35 |
| operations (27 years) (number of round trips per day) | cars | 0 | 0 | 10 |
| | trucks | 4 | 1 | 5 |
| | buses | 0 | 0 | 8 / 4 ^(b) |
| | total | 4 | 1 | 23 / 19 ^(b) |

^(a)Traffic numbers are estimates based on project description as of May, 2005.

^(b)Weekday / weekend numbers.

The greatest impacts of the project in relation to traffic volumes will occur during the construction phase, especially along RN44 between Ampitambe and Moramanga. Numbers of trucks along the route will increase about 6% during construction and 2% during operations. Numbers of personal vehicles will increase by about 3% during both construction and operations. Numbers of buses will increase by an average of 4% during construction and operations, although the buses to be used will be larger than the types commonly seen in Moramanga under baseline conditions. Because of economic effects of the project, additional traffic may result from the development of other businesses

and the work of contractors, which is difficult to predict quantitatively and has not been included in Table 5.5-2.

Based on the number of vehicles estimated in Table 5.5-2, the total distances to be traveled annually by project vehicles along the major access routes is summarized in Table 5.5-3.

Table 5.5-3 Vehicle Kilometres per Year

| Project Phase | Vehicle Types | RN2, Moramanga-Toamasina | RN2, Moramanga-Antananarivo | RN44, Ampitambe-Moramanga |
|---|---------------|--------------------------|-----------------------------|---------------------------|
| construction (3 years) (million km per year) | cars | 0 | 0 | 0.07 million |
| | trucks | 2.92 million | 0.19 million | 0.13 million |
| | buses | 0 | 0 | 0.07 million |
| | total | 2.92 million | 0.19 million | 0.27 million |
| operations (27 years) (million km per year) | cars | 0 | 0 | 0.07 million |
| | trucks | 0.73 million | 0.09 million | 0.04 million |
| | buses | 0 | 0 | 0.05 million |
| | total | 0.73 million | 0.09 million | 0.16 million |

Based on numbers of kilometres, the highest impact of the project will be along the RN2 between Moramanga and Toamasina. The highest impacts along all routes are expected during the construction phase.

Traffic volume effects will be most apparent in Moramanga, where existing traffic congestion is highest and where all three of the routes meet. The project is likely to increase traffic congestion in Moramanga, unless additional bypass roads are constructed.

Accident Rates

Existing accident rates (measured as number of reported accidents per one million motor vehicle kilometres driven) have been documented on the RN2 between Brickaville and Toamasina at 3.12 per million vehicle kilometres based on Malagasy government statistics. The road conditions along other parts of RN2 and RN44 are assumed to be equivalent to this, and accident rates are assumed to rise at a level proportional to increased traffic. Based on the additional estimated traffic volumes, impacts on accident rates have been estimated and are shown in Table 5.5-4.

Table 5.5-4 Changes in Accident Numbers Due to the Project

| | RN2, Moramanga-Toamasina | RN2, Moramanga-Antananarivo | RN44, Ampitambe-Moramanga |
|--|---|---|---|
| baseline traffic kilometres | 476,736 trips x 250 km = 119 million km | 1,094,288 trips x 130 km = 142 million km | 1,843,452 trips x 10 km = 18 million km |
| baseline accident rate | 372 per year | 443 per year | 58 per year |
| traffic kilometres per year during construction | Base + 2.92 million km | Base + 0.19 million km | Base + 0.27 million |
| traffic kilometres per year during operations | Base + 0.73 million km | Base + 0.09 million km | Base + 0.16 million |
| incremental increase (and % increase) in accidents (construction) (without mitigation) | 9 accidents (2.4%) | 1 accident (<1%) | 1 accident (<1%) |
| incremental increase (and % increase) in accidents (operations) (without mitigation) | 2 accidents (<1%) | 0 accidents (<1%) | 1 accident (<1%) |

Noise and Vibration Disturbance

Noise

The noise assessment of traffic focuses on motorized vehicles only. The primary sources of noise from motorized vehicles are:

- motors; and
- interaction of vehicle tires with the road surface.

The amount of noise generated by individual vehicles used for the project is expected to be similar to vehicles already in use in Madagascar. Therefore changes in noise level would occur based on the number of similar vehicles on the roadways.

The change in the total number of vehicles on the three public roadways being assessed is generally less than 1%. The changes in various vehicle types are also generally less than 5% for each category except for truck traffic between Ampitambe and Moramanga which ranges between 5.5 to 7% over a week. Changes in truck traffic are considered more important since trucks typically generate more noise than passenger vehicles.

The changes in traffic can also be stated from the receiving environment point of view as the number of vehicle “pass-bys” per hour. Vehicles generate noise each time they pass a noise receiver; each ‘pass-by’ is a noise event. Assuming 80%

of traffic occurs during daylight hours (taken as 14 hours per day) and that project-related traffic will also be during daylight hours, a change of between one and four vehicles per hour can be expected. On RN44 (the Ampitambe-Moramanga route), one to two trucks per hour can be expected. Table 5.5-5 provides an analysis.

Table 5.5-5 Number of Vehicle Pass-Bys (Noise Events) per Daylight Hour

| Vehicle Type | RN2, Moramanga- Toamasina | | | RN2, Moramanga-Antananarivo | | | RN44, Ampitambe- Moramanga | | |
|---------------------------------|-----------------------------|-----------------------|-------------------------|-----------------------------|-----------------------|-------------------------|-----------------------------|-----------------------|-------------------------|
| | Minimum of Weekend/ Weekday | Number Due to Project | Total Pass-bys per Hour | Minimum of Weekend/ Weekday | Change due to Project | Total Pass-bys per Hour | Minimum of Weekend/ Weekday | Change due to Project | Total Pass-bys per Hour |
| Construction | | | | | | | | | |
| private cars | 29 | 0 | 29 | 14 | 0 | 14 | 19 | 1 | 20 |
| transports for people (buses) | 20 | 0 | 20 | 12 | 0 | 12 | 12 | 1 | 13 |
| transports for goods (trucks) | 32 | 1-2 | 33-34 | 20 | <1 | 20-21 | 14 | 1-2 | 15-16 |
| two-wheeled vehicles, motorized | 80 | 0 | 80 | 20 | 0 | 20 | 204 | 0 | 204 |
| total | 161 | 1-2 | 162-163 | 66 | <1 | 66-67 | 249 | 3-4 | 252-253 |
| Operation | | | | | | | | | |
| private cars | 29 | 0 | 29 | 14 | 0 | 14 | 19 | <1 | 19-20 |
| transports for people (buses) | 20 | 0 | 20 | 12 | 0 | 12 | 12 | <1 | 12-13 |
| transports for goods (trucks) | 32 | <1 | 32-33 | 20 | <1 | 20-21 | 14 | <1 | 14-15 |
| two-wheeled vehicles, motorized | 80 | 0 | 80 | 20 | 0 | 20 | 204 | 0 | 204 |
| total | 161 | <1 | 161-163 | 66 | <1 | 66-67 | 249 | 0-3 | 249-252 |

Changes to noise levels on the project access road will depend on the amount of existing traffic. The amount of project traffic on this road is expected to generate the same number of noise events as traffic on RN44 – three to four total vehicles per hour and one to two trucks per hour during construction.

Vibration

The assessment of ground vibration from traffic focuses on large motorized vehicles (buses and goods transport trucks) only. The primary sources of vibration from motorized vehicles are:

- tires striking irregularities in the road surface (impact load); and

- oscillation of the vehicle suspension or “axle hop” (oscillating load) (Hunaidi 2000).

The amount of vibration generated depends on the speed of the vehicle, the condition of the roadway and the type or condition of the vehicle suspension. Vehicles used for the project are expected to be similar to other vehicles of the same class in Madagascar and will be expected to follow posted speed limits.

Routes RN2 and RN44 are paved roads in relatively good condition. The routes through Moramanga are well used and may have more irregularities (potholes and damage from use) due to the existing traffic levels. Changes to existing levels of ground vibration would occur based on the increase in vehicles due to the project. As stated in Table 5.5-5, one to two trucks per hour and one bus per hour may occur due to the project during construction, which is up to a 7% increase in these types of vehicles.

The amount of change in ground vibration along the project access road will depend on the amount of existing traffic and the roadway conditions. The amount of project traffic on this road may be as high as the project traffic through Moramanga (1 to 3 heavy vehicles per hour) and the road surface is expected to be graded gravel. Mitigation for vibration may be necessary if homes are very close to the roadway (within 200 m) and if road conditions deteriorate (such as after a weather event). This road will be widened and improved by the proponent, and will be maintained to help reduce vibration impacts.

5.5.5.3 Mitigation

Mitigations to protect against accidents and promote public safety will include:

- road improvements to minimize disturbance and risks especially at intersections where project roads meet public roads;
- workforce codes of conduct and training programs with respect to driving; and
- public education.

In Moramanga, the proponent will work with the municipal government to determine appropriate local procedures (routes and speed limits) for project vehicles moving through the town.

Mitigations for noise and vibration include:

- scheduling project traffic for daylight hours where possible to minimize sleep disturbance by increased noise events (this has been assumed in the analysis);
- scheduling large vehicle (trucks and buses) trips as convoys to reduce the number of times per day a disturbance may occur, if this option is preferred by noise receivers;
- maintaining vehicles in good condition to ensure they are no louder than other, similar vehicles on the roadways; and
- ensuring vehicles travel at reduced speeds to minimize impact and oscillation loads when homes are adjacent (within 200 m) to a roadway.

5.5.6 Conclusions

The project will result in traffic increases on the paved highways between Antananarivo and Moramanga, Toamasina and Moramanga, Ampitambe and Moramanga, and Ampitambe and the mine site. The greatest impacts of the project in relation to traffic volumes will occur during the construction phase, especially along RN44 between Ampitambe and Moramanga. Numbers of trucks along the route will increase about 6% during construction and 2% during operations. Numbers of personal vehicles will increase by about 3% during both construction and operations. Numbers of buses will increase by an average of 4% during construction and operations. Changes such as these are likely to result in proportional increases in accident rates, and will increase levels of noise, engine emissions, dust and vibration along the roadway. However, the implementation of safety measures (speed limits, drivers' education, public education, scheduling of vehicle passage, vehicle maintenance and case-specific road improvements) will reduce these impacts.

The mine access road from Ampitambe is likely to receive a high percentage of additional traffic, and some special mitigation such as home relocation may be required at the time of road widening. This road is under study. Villages will be avoided wherever possible.

Increased traffic levels may affect residences along the roadways, livestock and human safety through a combination of impacts to traffic congestion, noise, emissions, dust and vibration. In general, these effects are expected to be small, but adding to traffic congestion in specific locations, like Moramanga and Ampitambe, will result in an impact that is clearly observable to local residents.

6 RECLAMATION AND CLOSURE PLAN

6.1 INTRODUCTION AND GENERAL OBJECTIVES

Reclamation and closure of the mine site will be based on the following general objectives:

- Reclamation goals and objectives are being 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 rehabilitated to restore the site to forested habitat consistent with the surrounding zonal forest.
- The reclamation and closure design will ensure that long-term physical and chemical stability is provided.

The preliminary reclamation and closure plan is a living document that will be updated throughout the Ambatovy Project (the project) life to reflect changing conditions and the input of local authorities and stakeholders. In addition, revegetation research and implementation as part of progressive reclamation will also guide the refinement of concepts for final closure. More details of reclamation and closure planning are provided in Volume H, Appendix 7.

The Ambatovy-Analamay mine site is within a contiguous natural near-primary forest matrix at the edge of the Zahamena – Mantadia – Andasibe forest conservation planning area. Thus the primary goal of reclamation at the mine site will be to maintain biological integrity in terms of landscapes, ecosystems, communities, habitats, plant and wildlife populations, species and genes. Forest protection on the mining lease will be planned, implemented and enforced by means of a forest management agreement being developed by the project proponent with the Malagasy Forestry Service.

6.2 NO MINE OR EARLY MINE CLOSURE SCENARIO

The environmental management plan for exploration agreed upon between the project proponents and ONE states that rehabilitation activities will be ongoing following exploration regardless of whether the mine is developed or not. In response to this agreement, the project is conducting ongoing restoration activities on all sites, giving high priority to steeper-slope areas at the edges of the ore bodies.

In the case of a no-mine scenario, restoration of all roads and platforms will be performed. The project will fulfil requirements for a reclamation certificate to be issued by ONE based on the criteria of canopy closure and establishment of a progressive succession of vegetation communities.

6.3 MINE AND CLOSURE PLAN

The open pits will be developed using hydraulic excavators to excavate progressively lower benches, reaching maximum depths of 50 m below the existing terrain at certain locations. Following the completion of mining in any one area, waste overburden from another area will be placed in benches back into the mine. The benches will be graded into the slope and configured longitudinally to direct runoff to a lined channel or drop pipe where the flow can be discharged in a stable manner down the slope. Slope angles proposed in the current mine plan have been determined to be stable for mining, but additional investigations are required to determine if such slopes will be stable in the long-term considering the climate and nature of the material. At the end of mining, the open pits will each be partially but not completely backfilled with overburden. Several low-lying areas will form ponds once dewatering ceases. Consideration will be given to linking these ponds, where feasible, with first order streams in the area, which will assist in the development of these ponds as fish habitat.

All slopes will be re-graded and contoured to stable slopes considering the nature of the material, to ensure long-term stability. The open pit slopes and floor will be laterite soils without any organic content, and as with other portions of the site, will require amendments such as mulch.

Two waste overburden stockpiles (Ambatovy waste stockpile and Analamay waste stockpile) will remain at closure. In addition, a small ferricrete stockpile will also remain. The stockpiles will be developed early in mine development, consisting of the first waste material excavated from the open pits. The stockpiles will be developed with stable slopes for long-term physical stability and will be progressively reclaimed by revegetation as the stockpiles are developed, meeting both interim stabilization requirements for sediment and erosion control and long-term closure requirements.

Buildings at the mine site, most notably the ore preparation plant as well as any ancillary buildings, will be dismantled and removed from site following closure. Equipment and materials will be salvaged for reuse to the extent possible. Any equipment and materials without salvage value will be placed in the on-site landfill. Provided no other users are identified, all buildings will be removed

from site. Any concrete structures will be demolished to 0.5 m below surface grade and will be covered with overburden before revegetation.

6.4 HYDROLOGY

Runoff collection ponds located downstream from the stockpiles will remain in place throughout the operations phase and into closure until sediment monitoring indicates that revegetation measures are providing adequate protection to minimize erosion and sedimentation. Ponds will be reclaimed by draining, and the embankments will be breached to restore natural drainage. Disturbed areas (such as the breached embankments) will be revegetated.

Once revegetation is well established across the site, mine runoff collection facilities will be decommissioned by breaching to re-establish natural drainage.

6.5 WASTE MANAGEMENT

Unused chemicals will be removed from the site to be either sold/reused elsewhere or will be disposed of with other hazardous wastes as per the operations phase of the project.

An on-site landfill will be used over the life of the mine for the disposal of non-hazardous waste. At closure, any exposed portions of the landfill will be capped.

Any areas of known or suspected soil contamination, such as fuel storage and transfer areas, will be assessed for contamination. Petroleum hydrocarbon contamination will be remediated on-site.

6.6 WATER PIPELINE AND CORRIDOR CLOSURE

The 23 km buried pipeline used to transfer water from the Mangoro River to the ore processing plant will be left in place as its removal would cause unnecessary disturbance. Any surface expressions of the pipeline (i.e., valves) as well as the pumping station and associated diesel generator will be removed.

Pipelines and pumping systems drawing water from the mine runoff collection ponds for use in process at the ore preparation plant will predominantly be above grade. Above-grade portions of pipelines, as well as pumping systems, will be removed at closure, and salvaged for use by others within the region.

It is expected that transportation corridors will remain in-place for a post-closure period to facilitate site access for monitoring. Once the area has stabilized the road surfaces will be reclaimed unless decided otherwise by regional authorities. The road surfaces will be scarified, and recontoured to blend in with the surroundings, and revegetated. Temporary erosion control measures will be implemented as necessary until surfaces have sufficiently stabilized. Considerable experience in reclaiming old exploration roads has been gained on the project to date and will contribute to the methodology of road reclamation following mine closure.

6.7 RECLAMATION PLAN

6.7.1 Erosion Control

The following general mitigation options will be employed as appropriate to prevent water erosion:

- salvage topsoil where feasible (except ferricrete soils) 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 a protective vegetative cover is established;
- 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 parallel to slopes (NRC 1993). Other species can then be planted between the strips of Vetiver.

The following mitigation will be applied as appropriate to prevent the siltation of reclaimed watercourses:

- prohibit the operation of construction equipment close to the banks of watercourses where there is a risk of bank sloughing, failure of the vehicle crossing or flooding of the work area;
- excavate cross ditches to divert runoff away from watercourses;
- construct berms containing overburden, timber, lumber, sandbags, rock, straw bales on approach slopes and/or banks to divert runoff off the site and onto well-vegetated lands; and
- place sand bags strategically to help stabilize and add height to banks to prevent flooding of nearby areas especially where vegetation has been removed.

6.7.1.1 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).

The NRC (1993) has suggested that Vetiver has the following unique traits:

- controls erosion when planted in a hedge across the slope just one plant wide;
- certain types bear infertile seed ensuring it does not encroach and spread;
- the plants are hardy and have been documented to survive drought, grazing, fire and floods. They are not tolerant to freezing;
- they are deep-rooted plants with roots having a high tensile strength allowing them to hold the soil against erosion;
- inexpensive to establish and require low maintenance; and
- grow in diverse soil types include saline, acid and low fertility.

For this project, trials of Vetiver are proposed for the initial waste dumps that are established to evaluate the potential of this species for the overall mining program.

6.7.2 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. Further details on revegetation of the mine site are discussed in Volume J, Appendix 1.1, Attachment 3.

In the mining region, which includes the whole Antampombato basic intrusion (dated at the Cretaceous), three types of forests are distinguished based on geology and substrate, these include azonal (or atypical), transitional and mid-altitude zonal forests.

Forest protection on the lease will be planned, implemented and enforced by means of a forest management plan to be ratified by the Malagasy government; this management plan is currently in preparation.

Multiple-use forestry has been chosen as the long-term land use of the mine region because it reflects Madagascar's regional plan to maintain the Mantadia-Zahamena forest corridor and the Torotorofotsy Wetlands, including its watersheds, as a long-term conservation site. The zonal forest of the mine region constitutes the western limit of this corridor. As such, the mine region forms part of this extended conservation landscape of the current regional conservation strategy.

To assist in achieving the long-term reclamation goals, the following assumptions and observations can be made:

- In the long-term (> 50 years), the ligneous species composition of the natural forest is expected to be similar to that of the surrounding residual forest (transitional – zonal) that is outside the mine footprint.
- The dominant type of substrate to be reclaimed is deeply weathered soil that is prone to sheet and gully erosion and could produce high loads of suspended solids if no adequate erosion control measure is being applied.
- The soil substrate is nutrient depleted and the creation of an organic layer to enhance soil aggregation and plant growth is required; mulching will be needed.
- Mulch from native vegetation (clear-cuttings of forests on the footprint) is of high quality but the available quantities produced will not suffice to satisfy the demand over time; other types of mulch, such as Eucalyptus, will have to be produced.

- Salvaging topsoil for subsequent site preparation is not practical as the topsoil properties are not suited for storage (top soil is more root mats than humus), quantities are insignificant and forest top soil extractability on ferricrete and transitional substrate is not feasible.
- A proactive testing and trial program to assist in improving rehabilitation protocols will be established to optimise rehabilitation methods and techniques.

6.7.2.1 Proposed Revegetation Phases

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.

Considerable opportunity for progressive reclamation exists throughout the 20-year mine life, as well as the subsequent seven years when the low-grade ore stockpile will be processed. Final closure will involve an “active closure” period starting in Year 28, in which the bulk of the physical rehabilitation work will occur, followed by a post-closure monitoring period. For planning purposes it is assumed that the active closure period will be five years, followed by a post-closure monitoring period of 10 years (15 years total).

6.8 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. In addition, periodic water quality analysis will be conducted to ensure chemical stability within the area.

7 ENVIRONMENTAL AND SOCIAL MANAGEMENT PLANS

Volume H, Appendix 6 contains a detailed outline of the Environmental and Social Management Plan (ESMP) for the Ambatovy Project (the project). Components of this plan apply to all project sites and include:

- Health and Safety Management Procedures;
- Emergency Contingency Plans;
- Waste Management Plans;
- Noise Management Plans;
- Materials Management Plans;
- Soil Management Plans;
- Water Management Plans;
- Air Quality Management Plans;
- Flora Management Plans;
- Fauna Management Plans;
- Aquatic Resources Management Plans;
- Human Resource Development Plans;
- Procurement Plans;
- Workforce Management Plans; and
- Re-Settlement Plans.

This section provides highlights of selected mitigation and monitoring that will form part of the management plans specific for the mine site. More detailed information is provided in the mitigation and monitoring sections of each Environmental Assessment (EA) discipline section. Mitigation and monitoring is divided into three sections: Section 7.1 presents key pre-construction work to be done; Section 7.2 presents activities to be performed for key management plans during operations; and Section 7.3 presents activities to be completed for key management plans during reclamation and closure.

7.1 PRE-CONSTRUCTION STUDIES

7.1.1 Water Management Plan

As part of the water management plan, ephemeral pools to be protected in on-site azonal areas will be assessed for sensitivity to acidification before the project begins. Water samples will be analyzed and if found to have chemical properties sensitive to acidification, a monitoring program will be developed and implemented for the operations phase.

Studies will be conducted related to total suspended solids (TSS) in flows from the mine during severe cyclones under baseline conditions. Predictive modelling is being conducted for greater than 1:10 year storm events.

7.1.2 Flora and Fauna Management Plans

Taxonomic studies will be completed before construction begins, including inventories at onsite and offsite areas. Flora species of concern lists will be re-assessed as the updated species distribution in these areas is verified. Off-site fauna surveys will focus on key species that are found on-site and close to the mine, especially rare species such as the two snakes new to science only found on the mine footprint.

In addition, a forest management plan will be developed for the mine area, with the purpose of protecting key buffer forest habitats as well as providing areas for productive land use.

7.1.3 Fish and Aquatics Management Plan

An offsite azonal protection area survey of ephemeral ponds will be conducted to determine if similar biological properties exist to mine site footprint ponds.

7.2 CONSTRUCTION AND OPERATIONS PHASE ACTIVITIES

7.2.1 Water Management Plan

To ensure that water flow volumes downstream from the mine are not substantially lowered, an intake pipeline will be constructed to bring water from the Mangoro River. Suspended solids will be monitored in the Mangoro River immediately downstream during construction of the Mangoro Intake.

Runoff and sediment controls will be implemented during site clearing and preparation. Runoff from project areas will be contained for settling and treated if necessary, using flocculants, prior to release into the downstream water basins. Runoff from active pit sumps will be diverted directly to the ore preparation plant if the pit is deemed to contain elevated levels of chromium. Runoff and clarification ponds will be managed to replicate the natural variability associated with high and low flows. Storage will be provided in the runoff collection ponds to attenuate peak flows.

Stream flow monitoring will be conducted in basins downstream from the mine to help define flow variability and to ensure downstream flow needs are being met, at least to the extent that they are met under baseline conditions. Water quality will be monitored at all clarification pond outlets, and downstream areas including the Torotorofotsy Wetlands during both wet and dry seasons.

7.2.2 Flora and Fauna Management Plans

Two on-site protected areas will be established on areas of azonal habitat near the mine. An additional azonal off-site conservation area at Ankera will also be established, pending confirmation that this is a suitable site.

Vulnerable plant and animal species will be translocated before construction. Plants will be transplanted, cultivated or propagated within appropriate facilities, and will be re-introduced to other lands or reclaimed areas as appropriate. Where feasible, selected listed International Union for the Conservation of Nature (IUCN) and Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) fauna species will be translocated to similar habitats. Monitoring will be carried out to determine the success of such translocation and transplanting activities.

The ecological stability of azonal conservation areas will be monitored, especially with reference to effects of air emissions and edge effects. Research-based reclamation trials will be established to test the success of different reclamation techniques.

A consultation process will occur to determine whether the forest management plan affects land use capability of specific individuals in a net negative manner, either due to loss of resource or change in access. Unresolved claims will be compensated for.

7.2.3 Fish and Aquatics Management Plan

A fish salvage program will move salvaged endemic fish to similar or suitable natural habitats (if available) before the disturbance of key water bodies at the mine. Malagasy expertise will be used to help evaluate long-term conservation management techniques downstream of the mine.

The water management plan describes means by which sediment and water quality will be maintained and monitored during mine construction and operations to mitigate effects on downstream habitats. As part of these monitoring efforts, downstream aquatic habitats will also periodically be observed. The loss of habitats within the mine disturbance area will be compensated for through the conservation of offsite areas that include ponds and other aquatic habitat. Water quality (including pH) will be monitored in on- and off-site conservation areas.

The Mangoro River intake will be properly screened to prevent the entrainment of fish.

7.2.4 Human Resource Development Plans

The project will establish training and education programs to meet the needs of the project and assist in the future needs of the region. In addition, the project will work with regional governments and stakeholders to assist in further development planning in the Moramanga and other nearby communities.

7.2.5 Procurement Plan

A procurement plan will optimize involvement of local businesses initially and will increase their involvement over time.

7.2.6 Other Socioeconomic Management Activities

An HIV/AIDS program will be established and will be operational before project construction begins.

The proponent is also committed to participate with government and NGO's in a range of community-based development planning initiatives in the project area. This participation will help integrate various project mitigations into related initiatives being led by others.

7.2.7 Emergency Contingency Plans

Mitigation for possible natural risks posed by both the collection and clarification ponds and the waste dumps and excavated slopes include:

- regular inspections and monitoring of hillslopes;
- completion of maintenance measures;
- embankment freeboard;
- spillway;
- geotechnical testing of tailings, fill, waste overburden and foundation materials;
- slope stability analyses;
- international standards for acceptable Factors of Safety;
- design earthquake 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; and
- storm routing design.

7.3 CLOSURE AND RECLAMATION ACTIVITIES

7.3.1 Water Management Plan

The mine will be reclaimed progressively throughout operations. Closure topography at the mine will be configured to ensure that drainage areas of each sub-watershed are close to pre-development conditions. Vegetation will be re-established progressively on areas in which mining has been completed.

7.3.2 Flora and Fauna Management Plans

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.

7.3.3 Fish and Aquatics Management Plan

At closure, drainage patterns will be established linking to natural watercourses at the edges of the development area. Forest cover and riparian habitat will be re-established along rehabilitated watercourses and standing water bodies. Any “extirpated” endemic species from aquarium and captive breeding programs will be re-introduced, if suitable habitats exist for their survival.

The concept and potential for an artisanal fishery, using suitable endemic species, will be discussed for the mine end pit lakes. Closure monitoring of species re-introduction and effectiveness will be done to assess the development and success of artisanal fisheries.